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Design tool for offshore wind farm clusters

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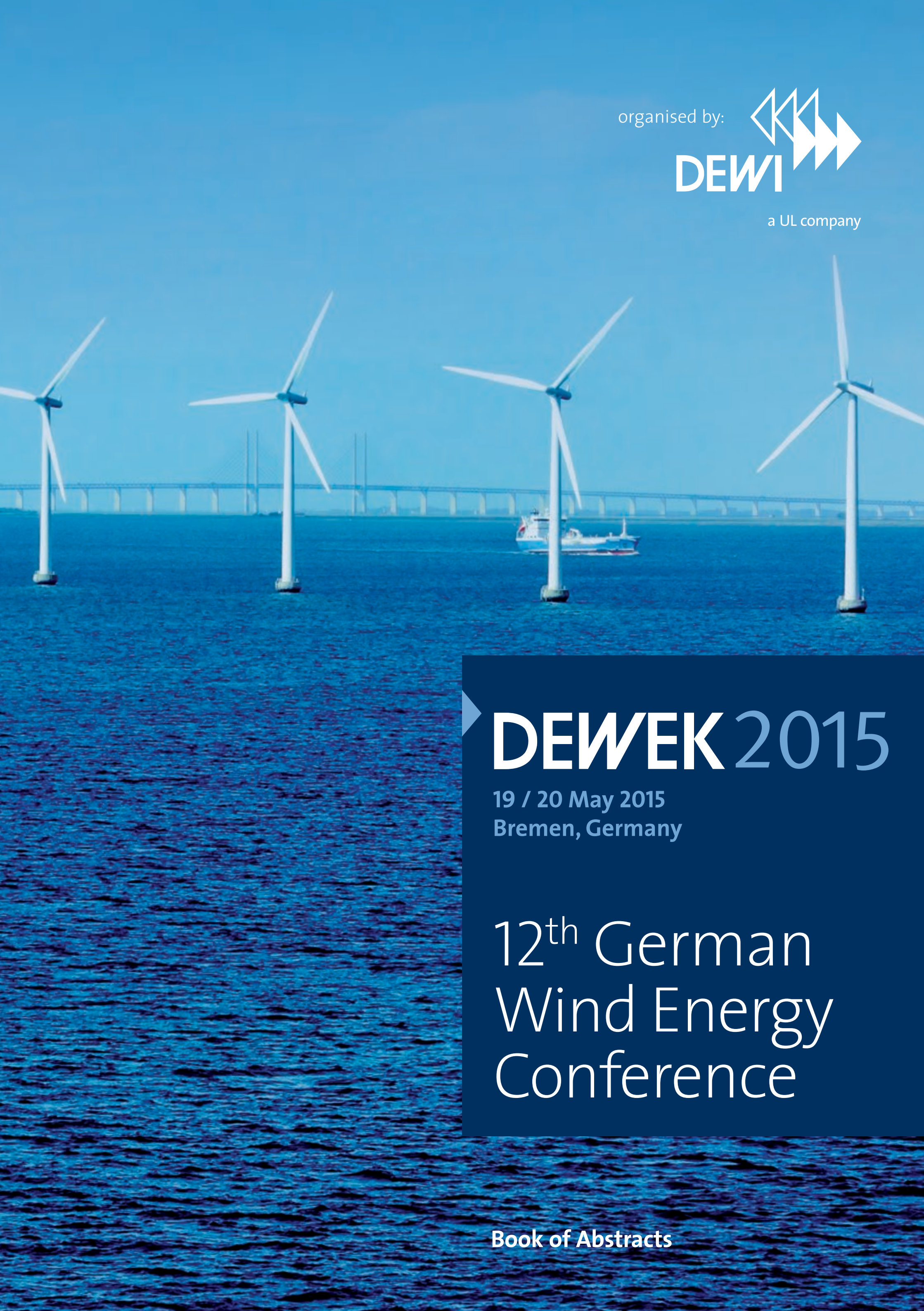
Published in:
DEWEK 2015, 12th German Wind Energy Conference. Book of Abstracts

Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record



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DEWEK 2015

19 / 20 May 2015
Bremen, Germany

12th German Wind Energy Conference

Book of Abstracts

Sigmar Gabriel
Federal Minister for Economic Affairs and Energy

MESSAGE OF GREETING BY SIGMAR GABRIEL PATRON DEWEK 2015

Wind power is the workhorse of the German Energiewende (energy transition). It accounts for every third kilowatt hour of electricity generated from renewable energy sources in Germany. Wind energy thus made a significant contribution towards achieving last year's record level of 27.8 percent of renewables in our electricity mix. For the first time, more electricity was generated from solar, wind, hydropower and biomass than from lignite. It is our intention to ensure that this positive trend continues, especially by making more use of offshore wind energy and by developing further suitable onshore sites for wind energy.

Last year's amendment of the Renewable Energy Sources Act (EEG) marked an important step forward for wind energy. With annual expansion corridors of 2,500 MW for onshore wind plus repowering, and of 800 MW for offshore wind and the extension of the compressed-tariff model, we are securing the home market of the German wind industry for the long term. We are thus responding to the special importance of the wind sector in terms of energy, structural and industrial policy. Wind power technology has developed into a showcase of German industrial performance and has created thousands of new jobs.

If we are to make full use of the potential, however, the wind industry will now need to play its part as well. We need further improvements in the cost efficiency both of investments in and of the operation of wind turbines, as well as a greater contribution towards energy and grid security, and more research and development to achieve this. This is also the aim of the funding provided towards energy research by the Federal Ministry for Economic Affairs and Energy. The key challenges here are to improve the yield and the reliability of wind turbines over a period of more than 25 years.

A major factor in the continued expansion of wind energy will be the integration of the electricity into the public electricity grids. We need more research into the grid connection of offshore wind farms, load and production management, wind-specific aspects of energy storage and the improvement of wind forecasts.

German companies, universities and research institutes are among the global leaders in the field of wind energy technology. Through their intensive cooperation, they are helping to secure access to international markets. The German wind industry is competing successfully with specific solutions for the deep-sea application of wind turbines, for rotor blade and turbine concepts for cold climates, and for the environmentally compatible design of turbines and installation processes. The Economic Affairs Ministry is giving intensive backing to these efforts, with a view to achieving a high level of value added in Germany whilst also reducing the industry's dependency on the domestic market by boosting the ratio of exports.

An exchange of experience between wind turbine manufacturers and component suppliers, universities and research institutes is of great importance for a successful development of wind energy. The large number of international participants and the wide range of conference topics are proof of DEWEK's position as a leading wind energy conference.

I wish all participants at DEWEK 2015 an interesting and successful conference.

Yours sincerely,
Sigmar Gabriel
Federal Minister for Economic Affairs and Energy

Olaf Lies

Minister for Economic Affairs, Labour and Transport of Lower Saxony

WELCOME ADDRESS BY OLAF LIES

Dear Participants of DEWEK 2015,

since the first DEWEK, already 23 years ago, wind energy development has experienced rapid growth. Whereas in 1993 the wind energy capacity installed world-wide amounted to just about 3,000 MW, in 2014 4,750 megawatts of new capacity were installed onshore in Germany alone. Additionally, offshore wind energy in Germany reached an installed capacity of approximately 1,400 MW by the end of the year. These figures show that wind energy has evolved from a marginal phenomenon to an important part of our energy supply system.

Lower Saxony with its many wind-rich sites in coastal areas has a significant share in this development. Approximately one quarter of the wind energy capacity installed in Germany is located in this federal state. The continued development of wind energy, onshore and offshore, will strengthen the particular role of Lower Saxony in the energy transition. Wind energy plays a key role in making the energy transition a success, because only by making adequate use of existing potential, Germany will be able to achieve its energy and climate targets. The development of wind energy also has contributed significantly to the establishment of new companies in the region and has developed into a success story particularly in regions previously regarded as economically underdeveloped. In 2013 the number of people employed in Lower Saxony in the field of renewable energies was 55,000, of which 32,000 jobs were created by the wind industry.

The global new investment in renewable energies in 2013 was USD 250 billion minimum. By 2035 global investment in the supply of power and heat from renewable energies is expected to double. Therefore the energy transition in Germany and the global growth in renewables offer excellent economic and employment-related opportunities for Lower Saxony. For a further successful development of wind energy it will be important to continue reducing the costs of power generation, to improve the reliability of wind turbines and to advance system integration. Offshore wind energy, although still rather expensive in comparison with other renewable energy sources, can contribute to system stability and the security of energy supply due to a high number of operating hours and full-load hours.

DEWEK as a forum for exchanging ideas and networking for experts and stake-holders from research and industry has played an important part in the further development of wind energy for many years.

I wish all participants of DEWEK 2015 a successful conference with interesting discussions and valuable impulses for their work.

Yours sincerely,
Olaf Lies
Minister for Economic Affairs, Labour and Transport of Lower Saxony

DEWEK 2015

Dr. Joachim Lohse

Senator for Environment, Urban Development and Transportation, Bremen

WELCOME ADDRESS BY DR. JOACHIM LOHSE

The 12th German Wind Energy Conference DEWEK on 19 and 20 May 2015 will once again bring a large number of experts from the field of wind energy research and development to Bremen, which reflects the high priority attached to wind energy in the federal state of Bremen.

Since the beginning of the nineties, the city state of Bremen has been supporting the development of wind energy. Favorable conditions were established for the use of onshore wind energy and for attracting companies of the wind industry to the region. Today we can see the results of the political decisions and framework established during the past 20 years:

Bremen and the surrounding region have evolved into a center for wind energy. Numerous companies have set up business in the area and developed an excellent network. The University of Bremen und die University of Applied Sciences Bremerhaven have established a research infrastructure that is renowned nationally and internationally.

The use of wind energy also has developed rapidly. In 2014 Bremen was the federal state with the largest installed wind energy capacity in relation to its land area. In numbers of wind turbines installed in relation to area in 2014, Bremen came close behind the top-ranking state of Schleswig-Holstein. In 2011, the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) established a potential of approximately 200 megawatts of wind energy capacity, 80 % of which had already been developed by the end of 2014. For a densely populated city state with a small land area these are excellent results.

These figures also show, however, that there are only very few areas left that can be used for wind energy in future. The focus therefore will be on the repowering of existing wind turbines and the use of sites in or near industrial areas.

Offshore wind energy on the other hand has a much larger potential and has been supported by the state of Bremen for many years. The Offshore Terminal Bremerhaven (OTB) scheduled for completion within the next few years will provide another strong impetus for the energy transition and the growth of the wind energy sector. In 2014 the 258 offshore wind turbines installed in the German North Sea and Baltic Sea exceeded for the first time the total capacity of one gigawatt. Bremen is following this development with keen interest and pride and is relying on wind energy – onshore and offshore – as a means to achieve the energy transition.

The compromise achieved in the reformation of the Renewable Energy Sources Act (EEG) after an unnecessarily great deal of back and forth, has established a reliable foundation for the further development of wind energy. Wind energy will continue to play a leading role in the energy transition.

I am sure that DEWEK 2015 once more will give new momentum to the further development of wind energy technology. I wish the conference every success and all delegates a pleasant stay in Bremen.

Yours sincerely,
Dr. Joachim Lohse
Senator for Environment, Urban Development and Transportation of the Free Hanseatic City of Bremen

Photo by: Navina Reus

Francisco Martinez
(Managing Director)

Jens Peter Molly
(Managing Director)

OPENING WORDS BY THE ORGANIZERS

2014 has been a record year for wind energy in Germany. The new installed capacity of 4,745 MW onshore and 1,437 MW offshore marks a growth rate never reached before and underlines the importance of the German wind energy market, also on an international level. This development is to a great deal due to the nuclear disaster 2011 in Fukushima, Japan, after which Germany decided to opt out of nuclear power and to initiate a turnaround in energy policy. Throughout Germany new designated areas for wind energy use were assigned, and the development of these new wind farm areas is reflected by the current figures of new installations. A significant growth of wind energy is also to be expected for 2015 and 2016. This development is accelerated by the efforts of the market players to make use of the available sites before the implementation of the planned tendering system in 2017.

This fundamental system change of promoting wind energy in Germany and its perspectives for the wind industry in Germany, will also be an important topic at the DEWEK on 19/20 May 2015 in Bremen. Therefore, in addition to the traditional sessions with top-class technical papers, the organizers have included a panel discussion in the DEWEK program, on the first conference day, at which the subject „EEG 3.0 / Tendering System" will be discussed with key players of the industry.

As always, the exchange of specialist knowledge on current topics in the field of wind energy research and application will be in the focus of the 12th German Wind Energy Conference DEWEK 2015. The fact that the DEWEK has established itself as an internationally renowned technical-scientific forum for wind energy experts is shown once more by the high number of 200 abstracts submitted for the conference.

Quite a number of contributions deal with Remote Sensing Measurements, especially LiDAR measurements for onshore and offshore wind energy sites. In view of the growing dimensions of wind turbines, simulation and testing of rotor blades are also becoming more important. Furthermore, DEWEK 2015 features special sessions dealing with New Developments, Operational Experiences und Grid Integration.

Traditionally the two days of the DEWEK are also an excellent opportunity to meet colleagues from universities and research institutes as well as engineers and business partners from the industry. The accompanying exhibition where companies and research institutes present their products and services offers the chance to discuss technical details or simply have a chat with colleagues of other companies. With presenters and delegates from 20 countries the conference is also an ideal platform for keeping up-to-date with the latest developments in other countries.

To relax after a day of intensive talks and discussions, enjoy the conference dinner in the beautiful wine cellar of the historical Bremen Town Hall. Good food accompanied by drinks and live music will turn the evening into a perfect get-together at the end of the first conference day. In this spirit we warmly welcome you to Bremen and wish you an interesting 12th German Wind Energy Conference and many valuable new contacts and insights.

Francisco Martinez
Managing Director

Jens Peter Molly
Managing Director

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SESSION NO. 21: ROTOR BLADES
Room 3: Lloyd; Chairpersons: T. Lutz, H. Soeker

POSTERS
Room 4: Foyer

DEWEK 2015

SESSION NO. 1: NEW DEVELOPMENTS

Room 1: Borgward Saal

TUNED MASS DAMPERS FOR APPLICATION IN ONSHORE AND OFFSHORE WIND TURBINE TOWERS

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1. Introduction

The height of towers for wind turbines has been continuously increased in the last years. As a consequence, the frequencies of the tower eigenmodes decrease and the tower itself becomes more sensitive against excitation by wind. There are different measures available, such as passive and semi-active viscous dampers as well as tuned mass dampers (TMD), in order to reduce vibration amplitudes of the first and second tower eigenmodes. The design, properties and effect on the first and second eigenmode of wind turbine towers of passive TMDs will be presented in this paper.

2. Design, Properties and Effect of TMD

Different kinds of TMDs like pendulum in oil [1] or tuned liquid column dampers have been used in wind turbines in the past. The design of the TMD presented here depends on the principle of a damped physical pendulum. Therefore a mass in the range of 10t is fixed at the lower end of a long rod. The damping of the device is realized by use of either viscous dampers or magnetic dampers.

Fig. 1: TMD for 1st tower eigenmode

The frequency, mass and damping of the TMD must be adjusted according to the requirements of the tower. The rough tuning of the frequency around 0.25Hz for the first eigenmode is defined by the length of the rod. Additionally, a fine tuning of the frequency in the range of about 20% can be achieved by adjusting the pre-tension of an additional spring (not shown in Fig.1).
The mass is built up modularly so that it can be easily adapted to the effective mass of the tower eigenmode. It should be at least 2% of the tower's effective mass.

The optimal damping Dopt depends on the mass ratio of TMD-mass and effective mass of the tower mode. Dopt must be independent of temperature in order to achieve low deflection amplitudes of the tower in the whole operating temperature range. Therefore a new non-temperature sensitive damping device was developed.

The functionality of the non-temperature sensitive viscous damper as well as of the magnetic damper will be shown. In most towers the available space is limited. Therefore the deflections of the TMD must be restricted. The influence on the optimal damping due to these limitations will be discussed. The effect of a TMD on the vibration amplitudes of a tower will be evaluated by multi-body simulations under stochastic and harmonic excitations. Measurements in a tower without and with TMD show the effect of the TMD on the tower vibrations. Finally, the influence of waves on the vibrations of offshore towers will be considered.

3. References

[1] T. Faber, P. Dalhoff, Dynamic behaviour of oil dampers in wind turbine towers, Proceedings of 2002 Global Windpower Conference & Exhibition, Paris

MULTIDISCIPLINARY OPTIMISATION OF A SLIP SYNCHRONOUS PM GENERATOR (SS-PMG)

J.N. Stander[1], G. Venter[1] and M.J. Kamper[2]

1. Introduction

1.1 SS-PMG technology and operation
This compact dual PM rotor generator technol-ogy (Fig. 1) is most versatile. It can replace an entire geared drivetrain or only the generator in a di-rect-drive wind turbine design [1]. As a drivetrain the wind turbine rotor is directly cou-pled to the induction rotor and the stator is di-rectly coupled to the grid via a synchroniser.

During grid synchronisation the PM rotor hous-ing the two PM sets accelerates until the stator fre-quency matches the grid frequency. When syn-chronised, fluctuations in torque is to some extend smoothed by the slipping action be-tween the in-duction and PM rotors.

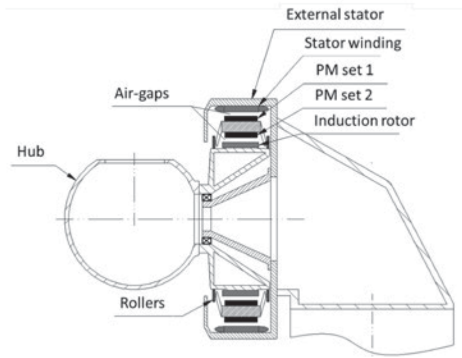

Fig. 1 SS-PMG design with radial flux paths.

1.2 Technological advantages
In concept, this machine combines the advan-tages of an induction-type machine with that of a permanent magnet synchronous machine. Both the induction rotor and the stator are ex-cited by PMs which are secured to the mid-rotor. The two sets of permanents have differ-ent pole counts which indicate that the induc-tion rotor and synchronous stator are not electromagnetically coupled. Such a character-istic yields an added design freedom. Early studies [1] showed that an overall machine ef-ficiency of 90 % at full load is possible. Such efficiency is comparable to that of geared and PMSG-converter fed drivetrains.

2. Multidisciplinary optimisation (MDO)

2.1 Process
The optimisation of a 50 kW SS-PMG proto-type involved the multidisciplinary feasible [2] MDO archi-tecture which, in turn, incorporated a robust gradient based optimisation algorithm. The problem decom-position concerns the cou-pled calculation of the elec-tro-magnetic, ther-mal and structural (Fig. 2) respons-es using commercial finite element codes. The MDO procedure and initial design results are dis-cussed.

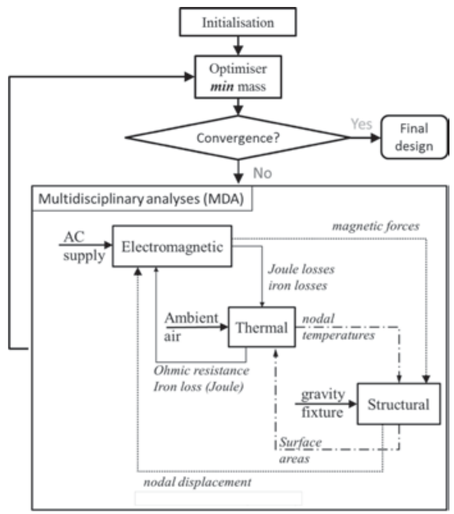

Fig. 2 Flowchart shows MDO architecture.

3. References

[1] Stander, J.N., Kamper, M.J. and Venter, G.: Analytic model-ling and optimization of slip syn-chronous permanent magnet wind turbine generator topologies. Wind Energy. Wiley on-line. DOI: 10.1002/we.1756
[2] Cramer, E. J., Dennis Jr., J. E., Frank, P. D., Lewis, R. M., and Shubin, G. R.: Problem formulation for multidisciplinary optimization. SIAM Journal on Optimization. Vol. 4, No. 4, 1994, pp. 754–776. DOI:10.1137/0804044

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DEVELOPMENT OF A MEDIUM SCALE RESEARCH HAWT FOR INFLOW AND AERODYNAMICS RESEARCH IN THE LARGE WIND TUNNEL OF TU BERLIN

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1. Introduction

The development of a medium scale research wind turbine is a part of the research project PAK 780 funded by the German Science Foundation (DFG). In this project six universities from all over Germany join forces and pursue fundamental research in the field of wind turbine aerodynamics, inflow turbulence as well as wake and flow control. The Modular Research Wind Turbine (MoReWiT) design and development is an integral part of this research program designed to assist the research tasks of all project partners.

The PAK 780 project consists of HFI TU Berlin, RWTH Aachen, Univ. of Oldenburg, Univ. of Stuttgart and TU Darmstadt and it is one of the major DFG funded projects in wind energy.

2. Design Concept

The MoRWiT turbine design is quite complex since it evolves around the four main design pillars: Sensor integration, flexible operation, modular construction and ultimate safety.

The custom designed blades are intended to avoid stall and to offer optimal aerodynamic performance while at the same time providing maximum internal space for sensor integration. The variable speed generator is designed to allow optimal operation throughout the operational envelope and is vertically located in the tower leaving amble space for the signal and air pressure slip-rings. A split belt-bevel gear reduction gearbox transmits the torque from the rotor to the generator, while a fail-safe pneumatic disc brake ensures the quick stopping action of the rotor.

A very large number of pressure sensors as well as rpm, force, torque and vibration sensors are integrated in the design making the MoRWiT a really unique research platform.

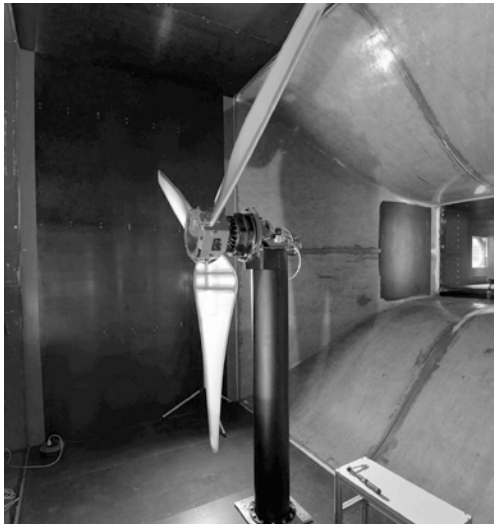

Fig. 1: The research wind turbine at the settling chamber of GroWiKa – TU Berlin

Fig. 2: Cut-view of the turbine nacelle, hub and tower

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DESIGN AND WIND TUNNEL TESTING OF A LEADING EDGE SLAT FOR A WIND TURBINE AIRFOIL

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1. Introduction

The continuous up-scaling of wind turbine rotors implies the necessity to implement further local control systems on the rotor blades, which would enable them to suitably react to the gustiness of wind. In this context, the design and wind tunnel testing of a leading edge slat for the DU 91-W2-250 airfoil, included in the BMWi funded project Smart Blades' reference blade [1], is here presented.

2. Numerical design

For the design of the aforementioned slat, direct numerical optimization was chosen as design method. The DLR optimization system CHAeOPS [2], using the SubPlex strategy as optimization method [3], and the DLR block structured FLOWer code [4], solving the compressible 2D RANS equations, were used for the optimization process.
Based on the rated tip speed ratio of the reference blade and on the position of the airfoil along the blade, the flow parameters were set at $M\infty = 0.1077$ and $Re\infty = 7.89e6$.
The resultant geometry of a first stage of the optimization with its characteristic lift coefficient values in comparison with those of the original profile are shown in fig. 1.

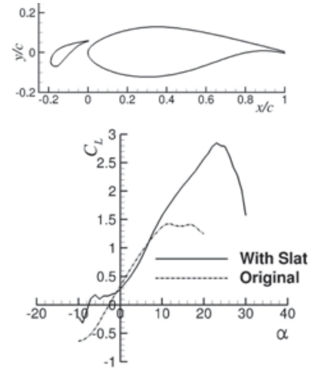

Fig. 1: Optimized slat geometry and CL values

3. Wind Tunnel Testing

For further validation, the optimal geometry is going to be measured at the University of Oldenburg's Göttingen type wind tunnel (Fig. 2). Numerical simulations and wind tunnel testing have already been accomplished for the original profile, showing good agreement.

The final geometry and its corresponding numerical and experimental analysis with their comparison are going to be presented in the future paper.

Fig. 2: Closed test section

4. References

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DEWEK 2015

ESTIMATION-BASED TORQUE TRACKING CONTROL FOR A NACELLE TEST RIG

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1. Introduction

1.1 Project DyNaLab

Reliability is always the most important issue of wind turbines. Recently test rigs of wind nacelles are becoming popular, which give the possibility to research the behaviour of the drive train under different load cases in laboratory repeatedly, so that the time-consuming and expensive field tests can be saved. With the test results the wind turbine can be optimized and the manufacture cost can be reduced. The test bench DyNaLab (Dynamic Nacelle Testing Laboratory), which is under construction by Fraunhofer IWES, can provide development testing, electrical certification, "End of Line" tests, etc.

1.2 Control problem

For realizing a dynamic and precise testing the controller is the key to whole system. The control of shaft torque should be fast and accurate. Meanwhile the controller should be able to improve the damping ratio of the test rig drive train. Because the drive train is elastic, the load torque is variable and only few measurements are available, the control problem will be very challenging.
To fulfil all these requirements this paper presents a modern estimation-based control strategy for the test rig. LQG (Linear Quadratic Gaussian) control algorithm is utilized, which consists of a Kalman Filter as the estimator and a LQR (Linear Quadratic Regulator) controller.

2. Estimation based optimal control

The test rig including the DUT (Device Under Test), as shown in Fig. 1, can be modelled as a 6-mass system. The air-gap torque of the drive motors M_a is the control input. The measured output is just the rotation speed of the first drive motor ω1. The LQR control can minimize the quadratic cost function of the tracking error Meanwhile it can achieve good balance between control performance and effort. LQR controller needs all information of the system. The unmeasured state variables are estimated by Kalman Filter including shaft toque M_{fl} and generator torque of the DUT M_g.The structure of the controlled system is shown in Fig. 2. The integration of tracking error is introduced in the system model to eliminate the steady state error. Thus the controller is robust to modelling error. The proposed control strategy is firstly verified by simulations with step response. The rising time of the torque control is about 23 milliseconds. There is no steady error. Torsional vibration is obviously suppressed. Furthermore the algorithm is tested with an electrical machine test bench, which has a similar structure as DyNalab and can be modelled as 2-mass system. The test results are consistent with simulations [1].

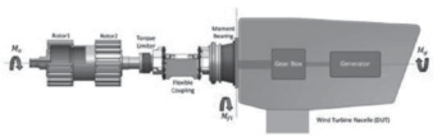


Fig. 1: Drive train of DyNaLab [1]

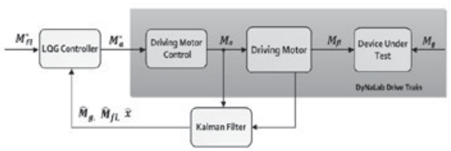
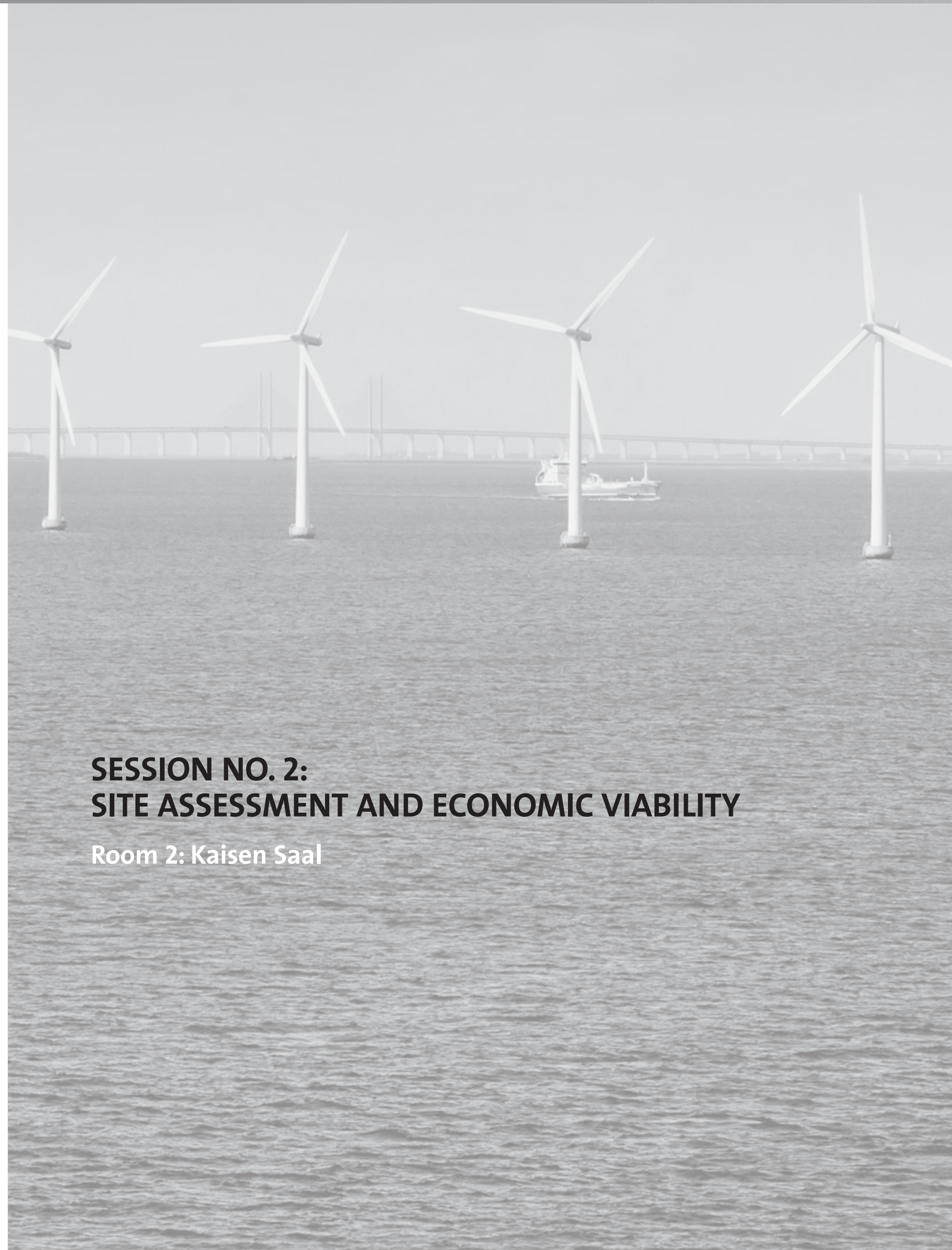


Fig. 2: Structure of controlled drive train

3. References

[1] Neshati, M. M.: State Space Drive Train Control of a Multi Megawatt Test Rig for Complete Wind Turbine Nacells, Master Thesis, University of Bremen, 2014



SESSION NO. 2: SITE ASSESSMENT AND ECONOMIC VIABILITY

Room 2: Kaisen Saal

TURBULENCE ASSESSMENTS IN THE ABSENCE OF MEASUREMENTS – AN EVALUATION STUDY

David Hilbert[1], Dr. Carolin Schmitt[2], Markus Weimbs[2]

1. Introduction

Accurate estimates of ambient turbulence are a pre-requisite for lowering uncertainties in the calculation of effective turbulences, which are a crucial parameter in the assessment of a wind turbine's suitability at a specific site [1]. Consequently, improved estimates of ambient turbulence enable an optimal wind park layout and lower the overall project risks.

In many cases the ambient conditions are assessed based on long-term measured data. However, for some sites there is no measured data available: This is particularly common e.g. in the German market, where developers refrain from costly measurement campaigns for yield estimations and rely on historical production data instead. For these sites, an economical alternative to measurements is to calculate the ambient turbulence intensity (TI) using analytical models, based on maps of a specific site's land cover or surface roughness (e.g. [2]).

The performance of these analytical turbulence assessments and the related uncertainties shall be evaluated in this study.

2. Approach

Ten different measurement sites in different wind park locations with varying terrain complexity are used to evaluate analytical turbulence assessments. For all sites data from tall measurement masts (reaching 80-120 m in height) are available for comparison purposes. The masts are equipped with high quality cup anemometers and have collected data for a period of at least one year.

3. Results

The study sheds light on two aspects of analytical turbulence assessments:
First, the capability of correctly predicting the ambient turbulence over height (vertical profile of TI). And secondly, the accuracy of the estimated distribution of TI over different wind speed bins at a certain height.

Whilst similar trends are observed for the vertical profiles of TI, it can be shown that the analytical assessment often fails to accurately predict the distribution of TI over the wind speed. This can lead to both under- and overestimation of TI for different wind speed bins. Finally, the performance is significantly influenced by the site's terrain complexity, which might make a case for more measurements in complex sites.

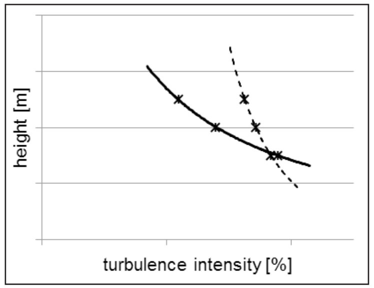


Fig. 1: Diagram of ambient TI over height at a sample site (predicted [- – –] and measured [——])

4. References

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FORESIGHTED PLANNING OF LIDAR MEASUREMENT CAMPAIGNS BY USING ERROR MAPS

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1. Introduction

Wind lidars have proven their high accuracy for measuring wind speed and direction up to great heights, especially in flat terrain, resp. homogeneous flow conditions [4, 6]. For complex terrain sites, e.g. low mountain ranges and forests, the flow becomes inhomogeneous. This leads to a significant, systematic bias of lidar measurements from the actual wind speed [1, 2]. In this report, we describe a new method that allows choosing the optimal location when planning a wind lidar measurement campaign. We show that mapping lidar errors results in more effective and accurate measurement campaigns. In compliance with the German technical guidelines, such as the FGW TR6 [3], this leads to lower uncertainties for wind resource assessments.

2. Method

Although it is possible to correct for the influence of inhomogeneous flow to some extent [5], this is always linked to an additional uncertainty within the wind resource assessment [3]. Therefore, locations with high systematic errors should be avoided where possible by thoughtful choice of measurement location.
For this, a method to pre-evaluate expected lidar errors within the area of interest is presented here.
Results from a computational fluid dynamics (CFD) model are post-processed in a way that the wind direction dependent lidar errors can be estimated and analysed for varying locations. By using this 'error map' it is then possible to choose optimal measurement locations with low systematic lidar measurement errors. Ideally this will make in-situ or post measurement corrections unnecessary.

3. Example results

The described method has been carried out exemplarily around Fraunhofer IWES 200 m measurement mast at Rödeser Berg, close to Kassel. The results emphasize the high variability in lidar error due to choice of location in complex terrain (Fig. 1). Highest underestimations of the true wind speed can be found at the hilltops while overestimations are located within valleys. As the local hill range is aligned orthogonal to the main wind direction (south-west), lidar errors in this region are even more severe when they are linked to the wind direction frequency distribution.

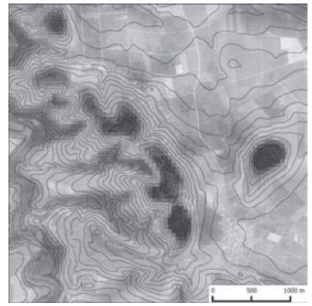

Fig. 1: Mean lidar errors at Rödeser Berg with underestimations (blue) and overestimations (red)

4. Conclusion

For lidar measurements in complex terrain appropriate methods must be applied to keep systematic measurement errors and in consequence uncertainties low. The method presented here will help project developers and wind energy consultants to plan their measurement campaigns more efficient, to reduce uncertainties and to gain higher project value.

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MOBILE LIDAR MAPPING OF UTILITY-SCALE WIND FARMS

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1. Introduction

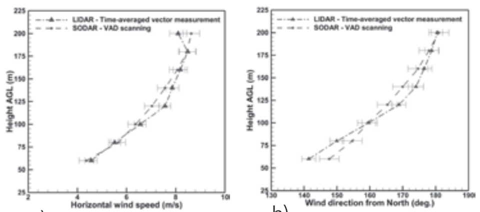
This work demonstrates the application of a single mobile-LIDAR to make measurements of the three-dimensional atmospheric flow and wakes in utility-scale wind farms. This demonstrated approach is advantageous compared to other remote sensing approaches, as a single mobile-based LIDAR with a lower cost of ownership within the context of the development and/or operating costs of wind farms is used. The utility farm scale measurements provide an improved knowledge of the actual characteristics of wakes in wind farms, and therefore the measurements are well suited to support the development of simulation tools that are used to model the atmospheric flow and wakes in wind farms and to optimise the micrositing of wind turbines.

2. Experimental Set-Up

The LIDAR system is installed in a custom-built mobile laboratory, windRoverII [1]. The LIDAR has a 3D scanning head that allows for volumetric scanning with an accuracy of 0.10 in azimuth and elevation. During measurements the LIDAR laser head is raised, by an elevator, through an opening in the roof of windRoverII; measurements can be made while windRoverII is driven.

3. Results

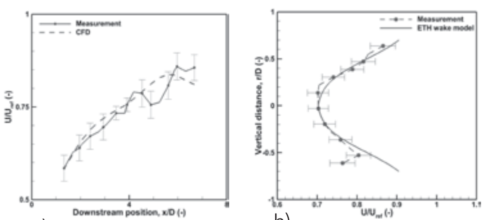
The measurements of the line-of-sight wind velocity from three positions are used to calculate the Cartesian components of wind velocity. This novel measurement technique has been validated by comparisons against a 98m instrumented met mast and SODAR at the Lindenberg Meteorological Observatory [2]. The RMS differences between vertical profiles of LIDAR and reference measurements of wind speed and direction are 0.3m/s and 3.40, respectively, Figure 1, validating the approach.



a) b)

Fig. 1: Comparison of single mobile-LIDAR measurements to SODAR. (a) wind speed and (b) wind direction.

In the final paper, the single and double wake interactions in two different wind farms, of capacity 25.8MW and 28MW, shall be detailed using this novel measurement approach. Figure 2 shows representative measurements of the wake of a 2MW wind turbine. The measurements are compared to CFD and semi-empirical wake model predictions.



a) b)

Fig. 2: Single mobile-LIDAR measurements of wake of 2MW turbine. Comparison of (a) streamwise evolution to CFD, and (b) vertical profile to wake model.

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STRUCTURAL CAPACITY CHECKS OF ADJACENT WIND TURBINES: HOW TO SUPPORT THE DEVELOPMENT OF NEW WIND FARMS IN GERMANY

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1. Introduction

1.1 Current problems with building permits

The installation of new and repowering of existing wind farms in Germany is often constrained by Building Authorities' requirements. According to the German DIBt Guidelines for Wind Turbine Generators (WTGs) [1], the planner of a new wind farm has to prove the structural integrity of not only the new WTGs but also all neighbouring ones, by showing that the increased park turbulence Ieff does not exceed the design turbulence. This analysis is usually carried out by independent engineering consultants. However, these consultants cannot perform a detailed capacity check of the WTG, by means of load simulations and FEM analyses, whether the design turbulence is exceeded. Instead the manufacturer of the WTG remains the only party able to perform these checks, i.e. a monopolist. In most cases, however, insufficient incentives exist for the manufacturers of existing WTGs to support the installation of the new WTGs in the vicinity. As a result, many WTGs in Germany operate with reduced power (below rated power) in order to reduce the Ieff of the neighbouring wind farms.

1.2 Micro economic perspective

From an economic point of view, this results in a "Deadweight Loss", since the potential resources in the wind are not being used efficiently due to the monopolist (cf. Fig. 1).

At present, no guidelines or regulations exists which could be applied to solve this problem. Thus, there is a need to develop a method, which can be used to satisfy the stakeholders (WTG manufacturer and wind farm developer) in such an event.

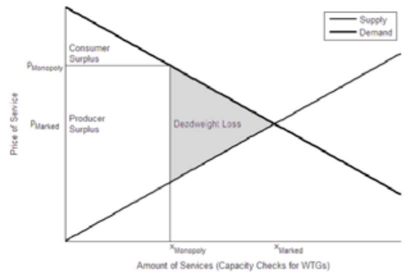

Fig. 1: Micro-economic description of problem

2. Solution

Incentives for the WTG manufacturer could be created by sharing the additional revenue generated through the manufacturer's own capacity check of the neighbouring WTG. In order to price this engineering service, a parameter study for a multi-megawatt WTG has been carried out with WindPro and the "Frandsen Model" [1], considering several controller strategies. The results show that a significant value can be generated for both the planer of the new WTG and the manufacturer of the neighbouring WTG (dAEP/dEqLR = 3%), see Fig. 2.
Applying this approach could solve the monopolist-issue and improve the business case for new wind farms and repowering projects in Germany.

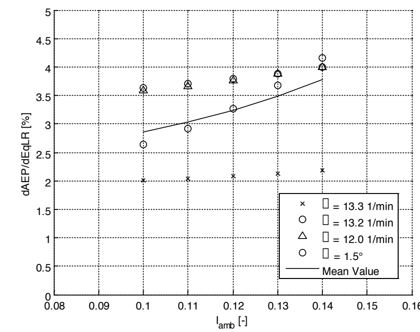

Fig. 2: Ratio of loss in energy (dAEP) and reduction of turbulence (dEqLR)

3. References

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FROM WIND SPEED TO MARKET VALUE AND FROM YIELD TO REVENUE

Heinz-Theo Mengelkamp*, Eckhard Kuhnhenne**

With the EEG 2014 (Renewable Energy Law) direct marketing of the electricity from wind turbines becomes compulsory. This makes the revenue of wind projects dependent on the volatile spot market price. Wind projects will no longer be evaluated based on the expected long-term mean annual energy yield alone but also with respect to the market value of the electricity produced. The market value is determined by the correlation of the time series of the energy production and the spot market price.

Based on hourly wind atlas data downscaled with the mesoscale model WRF from MERRA reanalysis data and the hourly spot market price time series an atlas of the market value of different wind turbine types is simulated for the period 2010 to 2013 with a spatial resolution of 5 km over Germany. The market value atlas shows the dependence of the market value on location (site factor) and turbine type/hub height (technology factor).

Similar of stepping from a regional scale wind atlas to a site specific wind potential analysis the necessity going from a market value atlas to a site specific revenue estimation is obvious.

Commonly the result of a site assessment is the long-term annual mean of the wind potential and yield to be expected in terms of frequency distributions. To combine the statistics with the spot market price hourly time series the statistics have to be transferred to a time series of the energy production or the spot market price has to be analyzed as the frequency distribution of wind speed. This will provide the wind farm developer, the operator or the marketer additional information to evaluate a wind project in terms of revenue instead of yield alone.

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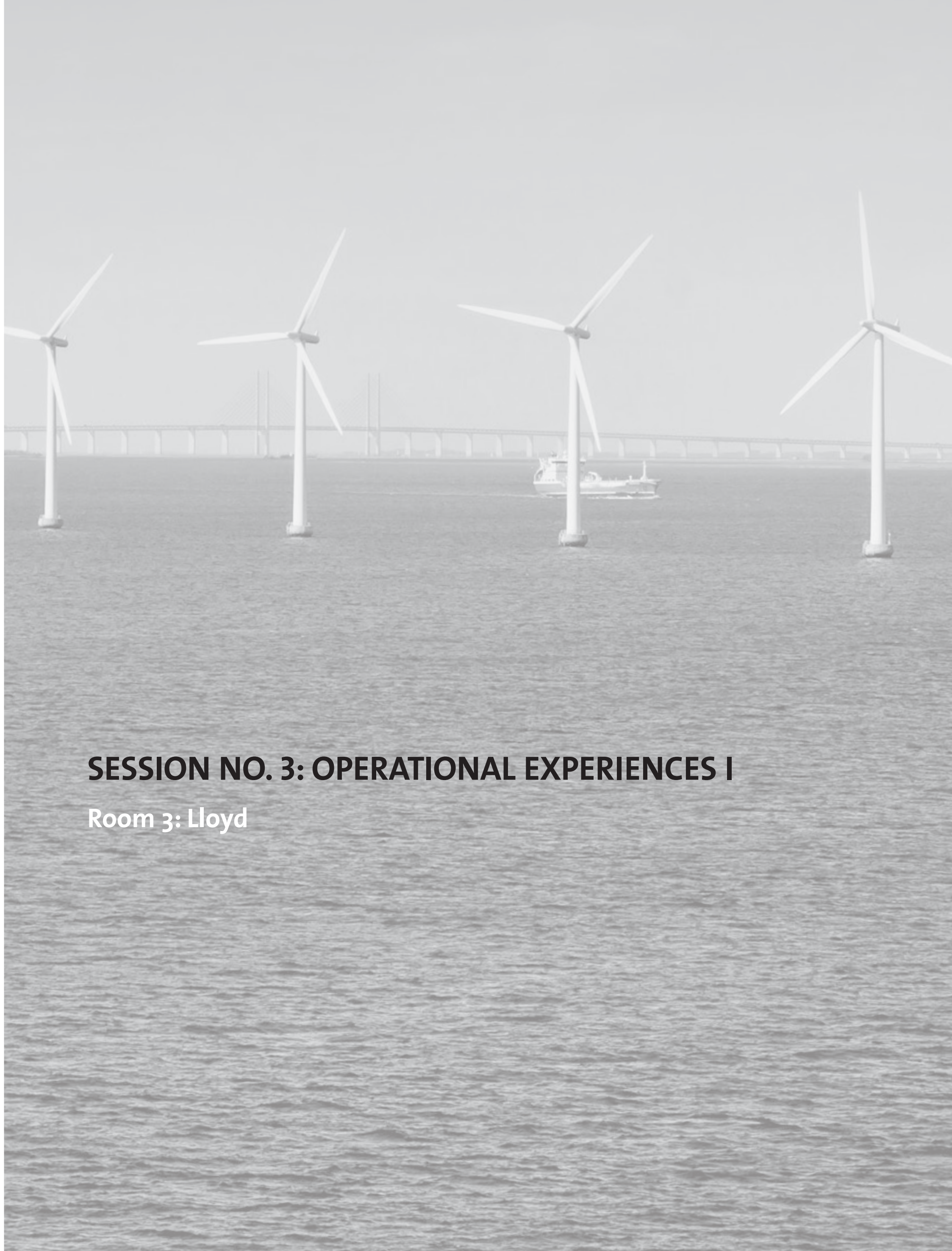

SESSION NO. 3: OPERATIONAL EXPERIENCES I

Room 3: Lloyd

PRACTICAL EXPERIENCES FROM A LOAD MEASUREMENT CAMPAIGN FOR THE ASSESSMENT OF THE REMAINING SERVICE LIFE OF WIND TURBINES

Michael Melsheimer**, Dipl.-Ing. René Kamieth*, Prof. Dr.-Ing. Robert Liebich*;
Dr.-Ing. Christoph Heilmann**, Dipl.-Ing. Anke Grunwald**

1. Challenge and approach

Currently, several thousand wind turbines in Germany reach the end of their 20-year design life. For the desired period of con-tinued operation, the German Building Authority requires an individual proof of the turbine's structural integrity and oper-ational safety based on the DIBt guideline (October 2012). A renewed calculation, a detailed inspection or a combination of both are proposed as applicable methods.
However, these methods may underesti-mate the individual turbine's actually en-dured loads since its structural response depends e.g. on the individual turbine set-tings, like intolerable blade angle devi-ations, or resonance issues. With a re-newed calculation based on the ideal tur-bine model and site wind data, etc., this is neglected. On the other hand, the inspec-tion detects damages only when it is quite late for preven-tive measures, since the increased loads have been acting already for a long time at the spot in question.
The presented research project proposes a new approach to enhance the above mentioned methods: The loads on the specific turbine are measured with an effi-cient load measurement campaign for several weeks to verify its structural be-haviour and loading. The results are com-bined with additional information of the turbine's lifetime for a holistic assessment of the actual lifetime consumption and thus the remaining service life.

2. Key features of the new approach

The new method for a realistic estimation of a wind turbine's remaining service life has the following key features:
- Individual assessment of the turbine's behaviour at its site: loads are meas-ured, not assumed
- Efficient measurement setup: a defined number of sensors employed for a lim-ited amount of time, i.e. several weeks
- Realistic construction of the endured load spectrum: load spectrum analysis and correlation of measured load spec-trum with the turbine's operational data for a reconstruction of its endured loads.

3. Field tests and first experiences

The load measurement system and the evaluation software have been success-fully developed and exten-sively tested. A measurement of several weeks in winter and summer at a small vertical axis wind turbine in urban wind conditions revealed unexpected high loads and resonance issues responsible for costly dam-ages after two years and disturbing building vibration. Since June 2014, the system is success-fully installed and continuously running in a wind farm at a 14 year old commercial 600kW pitch-controlled turbine with a steel tower. The measurement system com-prises at present:
- 5 strain gauges (tower top and base)
- 3 acceleration sensors (nacelle)
- 4 meteorological sensors (wind speed and direction, temperature, air pressure)
- 3 turbine data sensors (azimuth position, electrical output, rotor speed)
- Measurement PC with remote access

Operational data are available for several years to test the load reconstruction. Re-sults will be presented for the tasks:
- Optimisation of the load measurement including cost-effective in-situ calibration
- Measured load spectrum of older turbine
- Sensitivity analysis of the strategy to reconstruct the endured load spectrum

4. Acknowledgements

The doctoral stipend at TU Berlin is kindly granted by the Reiner Lemoine Stiftung and supported by Berlin-Wind GmbH. The measured wind turbine is kindly provided by Terrawatt GmbH.

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EVALUATION OF A WIND TURBINE FATIGUE LOAD MONITORING SYSTEM BASED ON STANDARD SCADA SIGNALS IN DIFFERENT WIND FARM FLOW CONDITIONS

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1. Introduction

Monitoring wind turbines fatigue loads using SCADA signals has been identified as an attractive alter-native to costly measurements, and to simulations that need very detailed information to model the turbine [1].
But despite of the potential benefits that a load monitoring system is expected to provide, like to help improve lifetime estimation or maintenance schedule, its usability is hindered by the lack of generaliza-tion if a data-driven model is used. This challenge has been identified for turbines operating in wake conditions [2], [3], where the prediction has a significantly lower coefficient of determination.
However, since the load monitoring system is aimed to be used as a sub-model in a more comprehensive wind turbine condition monitoring and prognosis system [4], which is expected to assist decisions based on probabilistic forecast, the emphasis in this contribution is placed on the probabilistic descrip-tion of estimated loads with such load monitoring system.
Such probabilistic description of fatigue loads should facilitate the operator to take decisions taking in consideration the uncertainty of the prediction, when combined with other condition monitoring technologies.

2. Investigation

The impact of different wind conditions on the prediction capability of a load monitoring system is in-vestigated using one year of load measurements from two wind turbines located in the offshore wind farm EnBW Baltic 1.
A sub-set of 10-min statistics from SCADA signals [5] is found after ranking the variables correlation with the load value of interest and discarding those providing redundant information. These statistics are used as inputs for a system based on feedforward neural networks, which estimate the mechanical loads in each wind flow condition based on a supervised learning algorithm.
Damage equivalent loads of flapwise blade root bending moment is used as target value to describe the methodology. A probabilistic description of estimated fatigue loads is presented for each wind flow condition, including different wake conditions, and the outcome of the monitoring system is compared to the load measurements for its discussion.
The research project "Baltic I" is supported by the Federal Ministry of Economy and Energy (FKZ 0325215)

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3D LASER OPTICAL MEASUREMENT OF THE ROTOR BLADE ANGLE

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1. Introduction

The accuracy in adjustment of the rotor blade angle is essential for an optimal behaviour of wind turbines. Already small deviation in the rotor blade angle leads to significant loss in energy production, increased vibrations and higher noise emissions.

WIND-consult developed a laser optical measurement method to verify the rotor blade angle. The measurement method results out of a R&D-Project subsidized by the state Mecklenburg-Vorpommern.

Fig. 1: scanning the profile at max chord

2. The method

The developed algorithm allows acquiring measurement points of the rotor as 3D data in a hub centre referenced coordinate system.

After referencing of the coordinate system the pressure side profile of the rotor blades are scanned. These profiles will be compared to the constructive given CAD model profile.

The key features of the method are:
- Verification of relative angle differences between blades and the absolute angle
- Verification of systematic errors in blade zero marking (manufacturing issues)
- Fixed referenced coordinate definition for CAD model comparison
- Acquisition of 3D measurement data for post processing and storage
- Up to 600m distance without reflectors
- No modification of the turbine
- Accuracy of ±0.1°

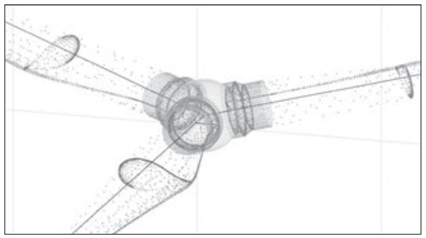

Fig. 2: measured profiles vs. CAD model

3. Results

Measurements on more than 60 wind turbines of the multi megawatt class are carried out in the last two years.

At approx. 35% of the turbines an aerodynamic unbalance greater than 0.5° was found. At 10% of the turbines the deviations were even greater than 1°.

On more than 50% of the turbines the absolute deviation to the specified angle was greater than 0.5° and at 15% even greater than 1°.

In one campaign a systematic manufacturing error in the blade zero marking process could be verified.

FIELD STUDIES ON ABSOLUTE BLADE ANGLE DEVIATIONS AT WIND TURBINE ROTORS AND THEIR IMPACT ON LIFETIME CONSUMPTION AND YIELD

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1. Turbine design certification stipu-lates tight rotor blade angle deviations

The correct rotor blade angle adjustment is essential for the optimum rotor efficiency and influences strongly the annual yield of a wind turbine (WT). Furthermore, abso-lute blade angle deviation (ABAD) and/ or relative difference between the blade angles (RBAD) increase the operational loads and component fatigue. This produces damage costs and damage-related stand still losses, and shortens service life, e.g. through stall vibration on the blades of Pitch WT. There¬fore, standards and guide-lines for WT design [1-3] require to define an ABAD limit, e.g. +/- 0.3° proposed in [3]. Correspondingly, the derived RBAD limit is 0.6°. This unfavourable setting with ABAD has to be included in the 20 year's design life fatigue load analysis. This implies that a WT matches only with the type certificate/ approval if its ABAD is below the limit during the entire service life.

2. Case studies on blade angle devi-ation at wind turbines

A first field study on RBAD at 237 WT measured without suspicion by independ-ent experts revealed that approx. 30% exceed their RBAD limit [4]. Then, the ABAD is as well above its limit. However, if ABAD is not measured, an unknown offset to the design blade angle remains causing e.g. persisting yield loss.
A new, second case study evaluates ABAD measurements at 239 WT (average rated power 2 MW), inspected by inde-pendent experts with or without suspicion. Using the above ABAD (RBAD) limit +/ 0.3° (0.6°) gives that for a share of
- 7% the ABAD is below this limit,
- 41% the RBAD is below, but the ABAD is above the limit and
- 52% both RBAD and ABAD exceed their limit.

All these WT had been adjusted before-hand by common OEM procedures, e.g. using the 0° marking plate. The number of misaligned blades per rotor is: 0 for 7%, 1 for 9%, 2 for 29%, 3 for 55% of the rotors. Hence, often more than one blade has an ABAD and for 84% RBAD evaluation alone is not sufficient.
For the individual 717 blades
- 21% have a tolerable ABAD,
- 35% have an ABAD towards feather and
- 44% have an ABAD towards stall.

The standard deviation is +/- 2.0°, the av-erage ABAD of the absolute values is |1.2°| i.e. 4 times the limit. For 57%, the ABAD exceeds |0.9°|, i.e. 3 times the limit, values go up to – 8.8° and + 11.8°. The high number of affected WT shows the necessity of the independent quality con-trol at each WT. The applied measuring method verifies directly the outer blade contour by taking for each blade a series of photos. The calibrated statistical evalu-ation has an accuracy of 0.1°.

3. Increased loads due to ABAD

A rotor with an intolerable ABAD produces intolerable loads compared to the design load spectrum. Load measurements at a 1.5 MW WT show, that pitching one blade by 1.0° off the design angle increases the ABAD-related damage contribution from 2% to approx. 25% in 20 years design life, which accelerates fatigue failures.

4. Case study on yield loss from ABAD

In a wind farm with 10 WT of the 1.5 MW class ABAD and annual yield of two years were evaluated. 9 WT were affected, the average yield loss was 10%. The yield loss per 1,0° mean ABAD of the rotor was 7.4%. This shows that ABAD measure-ments and adjustment have a very positive economic benefit.

5. References

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SURVEY ON JAPANESE WIND FARM O&M IN SMART MAINTENANCE PROJECT

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1. Introduction

Capacity factor of the wind farm of some in Japan is less than the plan. Hokkaido Bureau of Economy, Trade and Industry has reported about an operational realities of wind farms in Hokkaido [1] (Fig.1).

Fig.1 shows that some actual capacity factors are less than planned capacity factors. This report shows that 30 wind farm's capacity factors are under the minus 5% line from planned capacity factor. It is that most of the reason, time are spent on the fault accidents, troubleshooting, and maintenance of wind turbines.

Japanese wind farm is facing the issue of high turbulence, lightning, and typhoon. And some wind turbines have more downtime by some troubles and longer maintenance time in the complex terrains. Therefore, availability of wind farms are become lower. Since feed-in tariff, it is very important for wind energy developers to improve the operation of wind farm for up to the availability factor. t is one of the reason that there are less the number of skillful maintenance expert compared with European countries.

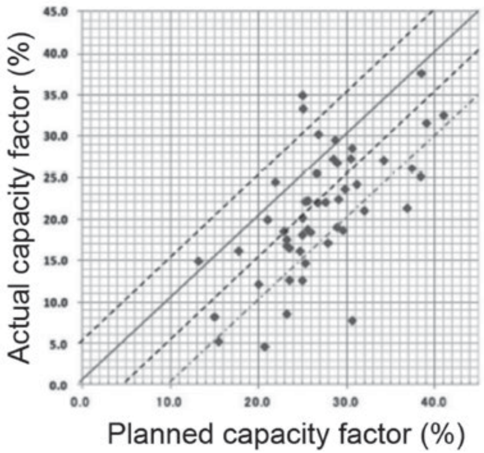

Fig.1: Scatter plots for annual planned and actual Capacity factor[1]

In response to issues, the authors started the project „SMART MAINTENANCE for the WIND ENERGY" funded by National institutes (NEDO,New energy and industrial Technology Development Organization) to improve maintenance efficiency. Project period is 2013 to 2015.

2. Examination method

This paper introduces about survey on Japanese wind farm O&M as a part of this project.

The authors conduct questionnaire and hearing. Questionnaire item are operational status, implementation system of O&M, failures and accidents, insurance. To some wind farm, we investigate SCADA data, operating records, failures, and accidents. We are analyzing the data to clear failure rate and downtime by wind turbine components in Japan.

Several studies about wind turbine failures and most frequent damaged components have already been published. Components affected and turbine downtimes were studied as part of the WMEP (Scientific Measurement and Evaluation Program) [2]. We will make a compare between study in Japan and the previous study in Germany, and clear the characteristic of Japanese wind farm. Future research will be carry out to extrapolate the O&M method for decreasing failure frequency and downtime.

3. References

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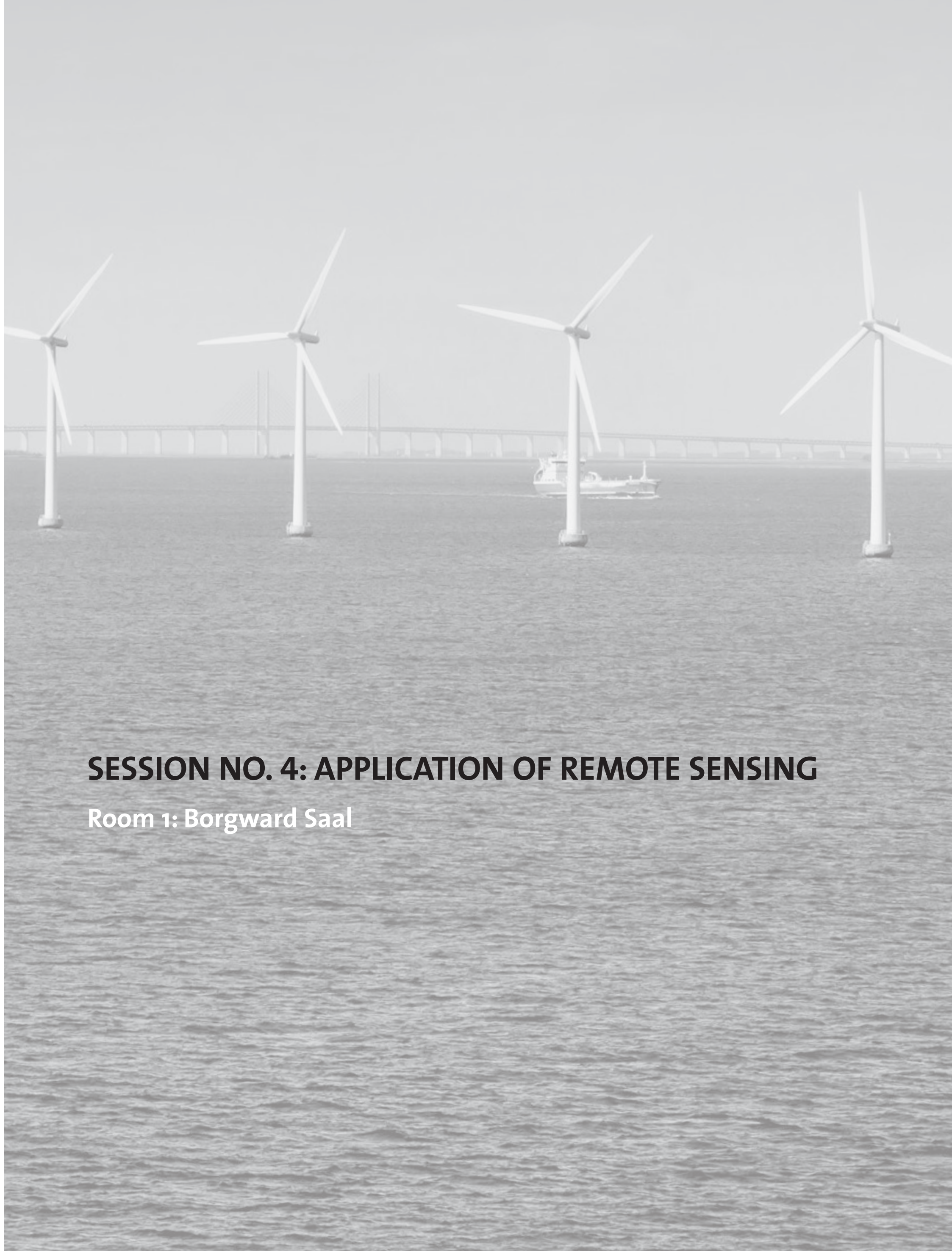

SESSION NO. 4: APPLICATION OF REMOTE SENSING

Room 1: Borgward Saal

LOW-LEVEL JET CLIMATOLOGIES FOR NORTHERN AND SOUTHERN GERMANY FROM SODAR AND RASS MEASUREMENTS

Stefan Emeis; Sophia Helgert*

1. Importance of low-level jets

Low-level jets (LLJ) are nocturnal wind speed maxima which form due to the sudden decrease of frictional forces during the evening stabilization of the atmospheric boundary layer. They cause enhanced vertical wind shear and shift the peak harvest of wind turbines to night-time when they occur.

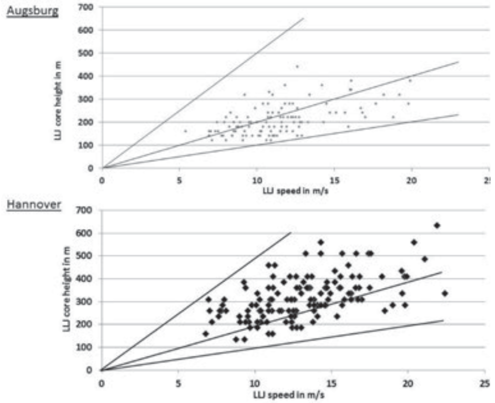

Fig. 1: LLJ core height versus LLJ maximum wind speed for Augsburg (top) and Hannover (bottom). Lines indicate constant vertical wind shear.

2. Remote sensing measurements

Measurements were made with SODAR in Hannover in the years 2001 to 2003 [1] and with a RASS in Augsburg in the years 2008 to 2014 [2]. Both campaigns included more than 600 days of measurements. A RASS captures the same wind data as a SODAR and additionally yields temperature data. Thus, Richardson numbers can be computed for the Augsburg data. The data have a temporal resolution of 10 to 30 min and a vertical resolution of 20 to 25 m. In both data sets, more than 120 LLJ cases were identified each. The search algorithm is described in [3].

3. Results

3.1 Grosswetterlagen

The favourite Grosswetterlagen for the occurrence of LLJ were identified for both sites. They differ slightly since LLJ occur most frequently at the fringe of high-pressure areas.

3.2 LLJ characteristics

LLJ occur in about 21 % of all nights in Northern Germany and in about 15 % of all nights in Southern Germany. The maximum speed of LLJ is mainly between 10 to 15 m/s in Northern Germany and between 7 to 13 m/s in Southern Germany. The height of the jet core varies between 200 and 400 m in Northern Germany and between 100 and 300 m in Southern Germany (see Fig. 1).

3.3 LLJ formation

LLJ are driven by the large-scale pressure gradient and speed up until the bulk Richardson number below the jet becomes as low as 0.15 to 0.25. This implies a wind shear of about 0.1 1/s (lowest lines in Fig. 1) in the layer below the jet.

4. References

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VERTICAL WIND SPEED DISTRIBUTION AND LOW-LEVEL JET AT BRAUNSCHWEIG AIRPORT

Belen Bernalte[1], Astrid Lampert[1], Detlev Wulff[2], Thomas Kenull[2], Kjell zum Berge[1]

1. The vertical wind speed distribution in the North German Plains

1.1 Motivation

For wind energy applications, the vertical profiles of wind speed determine the output and efficiency. Of special interest is the Low-level Jet (LLJ), a maximum in the vertical profile of the wind speed (Fig. 1). The Low-level Jet typically develops when the convective mixing of the atmospheric boundary layer ceases due to reduced solar irradiance, and a de-coupled residual layer forms above a ground-based temperature inversion.

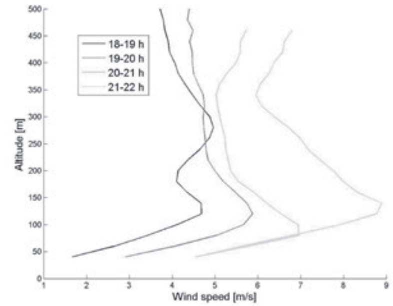

Fig. 1: Vertical profiles of wind speed for different times, with a maximum (Low-level Jet).

1.2 Wind speed distribution for 3 months

We present here the vertical wind speed distribution from 40 to 500 m altitude, observed with a wind lidar system (WindCube 8, Leosphere, France) for a three-months-period (winter 2013/14). The criteria of Low-level Jet events are chosen as described in [1]. For example, during the winter months, the most probable wind speed at 140 m altitude was 8 m/s (Fig. 2).

2. The influence of the Low-level Jet on the wind speed distribution

Low-level Jet events were identified on 46 % of all days during the 3-months observation period. This sounds a lot, however, based on mean values of 10 minutes, in 9 % of the data there was a LLJ event observed.

In the Weibull distribution, LLJ events were marked in pink (Fig. 2). It can be seen that LLJ events typically occur in the lower wind speed sectors, where they potentially increase the output of wind turbines.

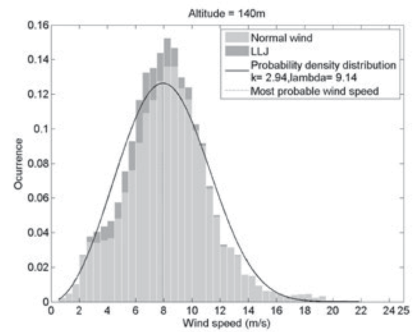

Fig. 2: The Weibull wind speed distribution for an altitude of 140 m. Wind profiles modified by a Low-level Jet are represented in pink.

3. Reference

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[1] Institute of Flight Guidance, Technische Universität Braunschweig, Braunschweig, Germany, +49-531-391-9885, Astrid.Lampert@tu-bs.de;
[2] Institut für Flugantriebe und Strömungsmaschinen, Technische Universität Braunschweig, Braunschweig, Germany

BIAS OF MEAN WIND ESTIMATE DUE TO NON-PERFECT AVAILABILITY OF REMOTE SENSING DATA

Gerhard Peters, Barbara Hennemuth*

1. Introduction

Lidar (Light Detection and Ranging) and Sodar (Sound Detection and Ranging) are remote sensing techniques (RSTs) estab-lished in various meteorological applica-tions since decades [1], [2]. They can be used for ground based measurement of wind profiles at heights embracing the whole range of a WEC rotor without the need of instrumented towers. The com-mon principle is the reception of backscat-tered signal from natural atmospheric tar-gets carried with the wind. An outstanding property of RSTs is the long term stability. Since the wind measurement is based on the Doppler effect no calibration is needed, which would be prone to change with time. A common weakness of RSTs on the other hand is their dependence on detectable backscatter signal from the atmosphere. The natural atmospheric re-flectivity is highly variable both for light and sound, and thus the received signal some-times falls below the detection threshold. This has been not considered as an issue so far for wind yield studies, because data gaps were be believed to be compensable by corresponding elongation of the sam-pling period. We will show that this is not a valid approach because we found that the mean value is biased in case of non-perfect availability due to low reflectivity.

2. Evidence of bias

Wind data obtained with a Doppler Sodar (Type "PCS2000-64") and a Doppler Lidar (Type "Stream Line") were analysed at height ranges, where nearly no gaps due to low signal occurred. "Low signal" means that the signal to noise ratio falls below the factory-set threshold T_low. The effect of data gaps, that would appear using a less sensitive RST system, was simulated by reanalysing the data with increased values of T_low. This procedure was repeated until most of the data were discarded. As an example the annual mean wind derived by lidar is shown as function of availability at different heights in figure 1. Similar ex-amples for Sodar will be presented.

Although the scattering targets for Lidar and Sodar are different, both techniques show a significant bias for non-perfect availability. The obvious explanation is that the reflectivity is correlated with the wind speed. Mechanisms that could be respon-sible for this correlation will be discussed.

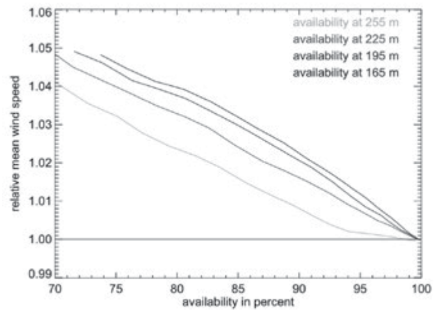

Fig. 1: Annual mean wind speed versus availability of data.

3. Conclusions

The effect of non-perfect data availability cannot be compensated by extending the sampling period. For keeping the bias safely within ±1% the sensitivity must al-low more than 95 % data availability.

4. References

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FIELD RESULTS OF NEW SODAR TRANSDUCER HORN

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1. Technology Development

1.1 Background

The KSN 1005A speaker is used in many phased-array SoDARs, including the ASC 4000, Fulcrum 3D, and the Triton Sonic Wind Profiler. This speaker has a flat frequency response, and features for high fidelity audio that reduce the directivity index.[1] These characteristics are not optimal for phased-array SoDARs. The low directivity index causes high intensity sidelobes, which can generate fixed echoes, and can cause beam angle errors due to internal reflections; and, the features necessary to create a flat frequency response reduce the horn's peak efficiency. Improving efficiency and directivity increases data capture rates, critical for wind resource assessment.

1.2 New speaker horn

Vaisala has developed a speaker horn, optimized for use in phased array SoDARs. The two key design elements are horn-length tuning and a prolate spheroid waveguide. Approximating the speaker horn as an open-ended tube, the resonant frequency, f_R = (nv)/(2L), where n is an integer, v is the speed of sound (ms-1), and L is the horn length (m). For L = 0.0753 m, at 20°C, the horn's 2nd harmonic frequency f_R = 4.55 kHz, optimally located in the center of a typical mini-SoDAR range, 4-5 kHz. The relative intensity improvement over the KSN 1005A, at 4.55 kHz, is 5.6 dB for a 0.0753 m length trumpet horn. The waveguide increases the peak intensity by 0.9 dB, for 6.5 dB total increase from the KSN 1005A. The waveguide increases the speaker's directivity index by equalizing the acoustic path length along the interior and exterior surfaces. The waveguide directivity index is 8.49 dB, 1 dB higher than the KSN 1005A speaker (7.49 dB) and 0.38 dB higher than the trumpet horn (8.11 dB).[2]

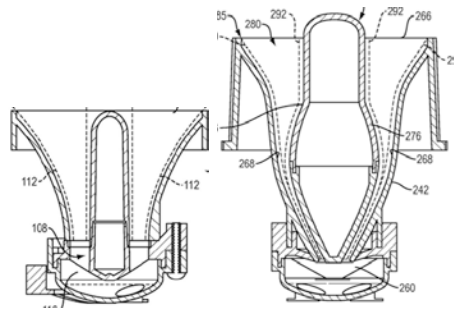

Figure 1 Comparison of prior art and new speaker horn

2. Field Results

2.1 Deployment

Out of roughly 100 SoDARs built with the Vaisala speaker, 25 have been installed at sites that are within 50 km of a Triton Sonic Wind Profiler operating with the KSN1005A speaker. These sites experienced comparable atmospheric conditions. Sites with significant differences in terrain have been excluded.

2.2 Data recovery

The Vaisala speaker horn increases the absolute data recovery rate at 120m, after all filtering, by 16%, reducing the amount of lost data by 50%. The increase in directivity index allows the SoDAR to operate accurately at multiple wavelengths, while remaining at or near fR. This change in operating strategy maintains the improvement during all atmospheric conditions.

3. References

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A NEW BISTATIC WIND LIDAR FOR HIGHLY RESOLVED WIND VECTOR MEASUREMENTS

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1. Introduction

In contrast to monostatic wind lidar systems tilting a laser beam into different directions to determine a wind vector in an almost homogeneous wind field (fig. 1 left side) the newly developed bistatic wind lidar (fig. 1 right side) allows to measure the velocity vector of single aerosols in a local highly resolved measurement volume in heights from 5 m to over 200 m.

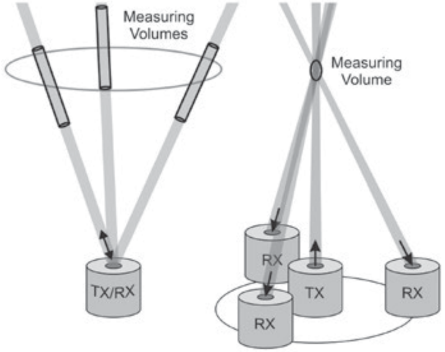

Fig. 1: Monostatic (left) and bistatic (right) wind lidar configuration

By applying one transmitting module (TX) and three receiving modules (RX) it has for the first time been possible to perform traceable lidar measurements of the wind vector in a well-defined measurement volume with a high local resolution of less than 1 dm^3 and a resolution of 0.1 ms^{-1} for the wind speed without any assumptions concerning the homogeneity of the wind field as conventionally required.
In complex terrain errors in the horizontal wind speed as measured by a conically scanning lidar system can be in the order of 10 % due to the lack of homogeneity in the wind speed [1].
As the newly developed bistatic wind lidar system measures the velocity vector of single aerosols, inhomogeneities of the wind field will have no influence.

2. First measurement results

With the realized bistatic wind lidar set-up on a platform of 2 m x 2 m it was possible to measure the wind vector in heights up to over 200 m in flat terrain. Comparison measurements with a commonly used monostatic wind lidar system (Windcube) have been performed (fig. 2 and fig. 3).

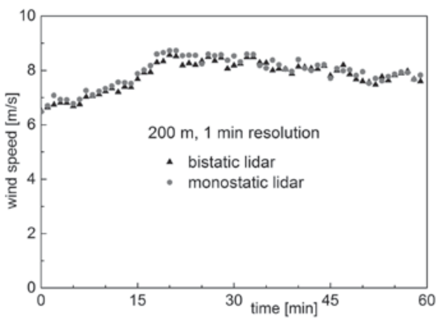

Fig. 2: Comparison of the measured horizontal wind speeds at 200 m

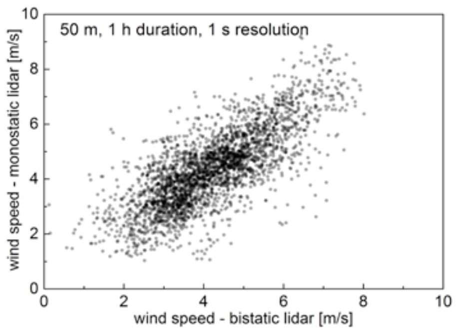

Fig. 3: Correlation of the measured horizontal wind speeds at 50 m

3. References

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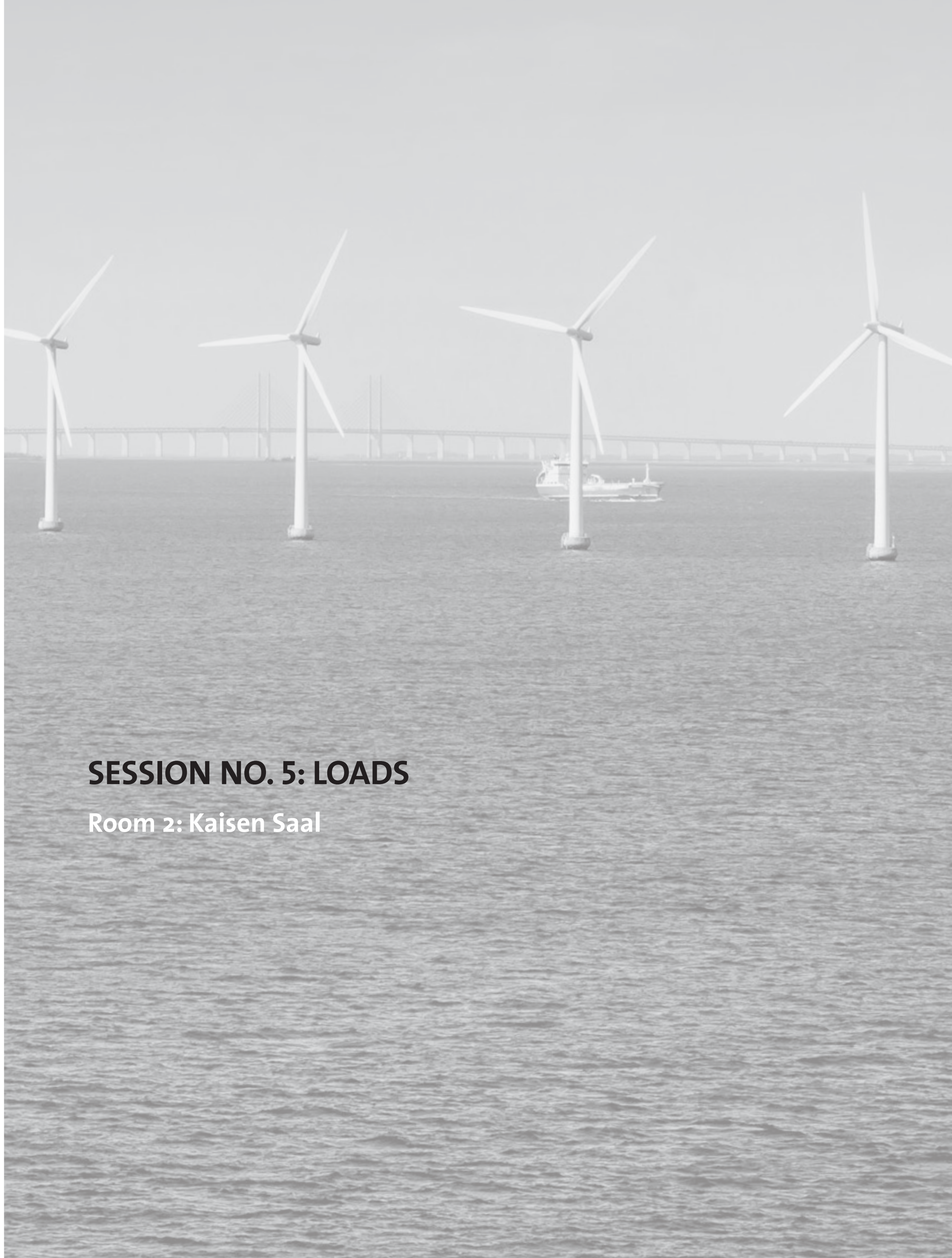

SESSION NO. 5: LOADS

Room 2: Kaisen Saal

NUMERICAL INVESTIGATION OF THE LOAD REDUCTION POTENTIAL OF A FLEXIBLE HUB MOUNTING ON TWO-BLADED WIND TURBINES

B. Luhmann[1], H. Seyedin[2], P. W. Cheng[1]

1. Introduction

In this paper an innovative load reduction system for the two-bladed Skywind 3.4 MW prototype is investigated. With a reduced number of components and a lower turbine weight as well as unconventional installation and maintenance opportunities a two bladed horizontal axis wind turbine is a potentially cost effective and competitive turbine design. Due to a complex dynamic behaviour and aerodynamic imbalances fatigue loads are the main design driver for this type of turbine.

In the presented load reduction system two additional rotational degrees of freedom are introduced between the tower top and the hub mount which allow the whole drive train to teeter and tumble around a spherical joint (Fig. 1). Motions are limited by using a restoring a passive or semi-active spring-damper element. Compared to a usually applied teeter hinge the rotor bending moments are therefore not fully decoupled from the turbine support structure, but load peaks are effectively mitigated, the damping of the aerodynamic response is increased and the turbine is stabilized in low-speed operation.

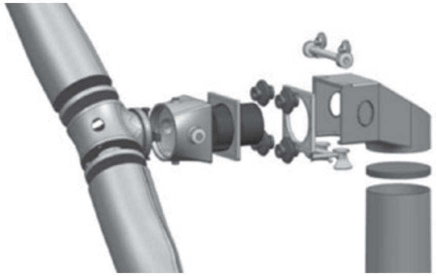

Fig. 1: Flexible hub mounting of the 3.4 MW Skywind prototype.

2. Methodology

In this investigation the load reduction potential of the described hub mounting in normal operation is estimated using numerical simulation. A high fidelity, full flexible model of the Skywind 3.4 MW prototype is set up in the multibody simulation software SIMPACK. Flexible bodies like blades and tower are modelled as modally reduced beam element bodies. The aerodynamic loading is calculated with a blade element momentum approach. An optimization of the connecting spring element parameters is performed in extreme sheared uniform inflow to derive a preliminary hub design and to distinguish the principal load reduction mechanisms. The high detail of structural modelling allows the comparison of different conceptual hub designs, in this case the flexible hub mounting, a teeter hinge and a rigid hub for reference.

3. Results

The frequency response of the flexible hub mounting in a fully turbulent wind field is analysed for the full range of wind speeds. A reduction of the 1P periodic rotating loads and their higher harmonics as well as the 2P periodic stationary loads and their higher harmonics respectively is observed. Compared to the rigid reference configuration the damage equivalent loading of most structural loads and especially the critical yaw bearing bending and torsional moments are significantly reduced.

Due to the specific hub design the rotational rotor position and the deflection direction of the hub mounting are unlinked. An analysis of the mounting kinematics shows that the neutral mounting position fully restores around the longitudinal axis of the beamlike rotor. Therefore mounting excursions and the risk of a destructive teeter end impact can be limited.

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STOCHASTIC MODEL FOR INDIRECT ESTIMATION OF INSTANTANEOUS AND CUMULATIVE LOADS IN WIND TURBINES: A SYSTEMATIC APPROACH FOR OFF-SHORE WIND FARMS

P.G.Lind[1], J. Peinke[1], M. Wächter[1,2]

1. Introduction

Important challenges in wind energy research still remain to be solved, particularly in what concerns the large wind fluctuations occuring with a non-negligible probability [1] and the optimization of power production as well as the high costs implied in the construction and operation of wind turbines together with the proper devices for controlling and monitoring them [2]. Alternative methods to indirectly estimate the necessary quantities for control and monitoring wind power production could help to mitigate these costs. Here, we propose a framework for reconstructing the statistical features of loads fluctuations which enables one to accurately estimate instantaneous and cumulative loads in wind turbines within one wind farm.

2. Data and Methods

The data analyzed was taken at Senvion's Alpha Ventus wind turbines, namely at AV4 and AV5, from 2012 to 2014, and is part of the project "Probabilistic loads description, monitoring, and reduction for the next generation offshore wind turbines (OWEA Loads)", funded by the German Federal Ministry for Economic Affairs and Energy. We analyze available loads at AV4 for deriving our model: the torque, the bending moments and acceleration measured at the blades and at the tower, taken at sample frequency of 50 Hz.
From the data we extract a recently proposed model [3] which yields a stochastic differential equation, which, combined with wind velocity measures is able to reproduce statistically the series of load measurements. The models derived from the measurements taken at AV4 are then applied to reconstruct each instantaneous and cumulative load at AV5 and compare them to the corresponding set of measurements. Previous studies have shown a successful estimation of torque series [3] and fatigue loads [4] in AV wind turbines. Here we investigate systematically if such approach can be extended to other loads at wind turbines.

3. Expected outcome

From our systematic approach we expect to propose valuable insight in which turbine loads are easily estimated only recurring to standard measurements, such as anemometer wind velocity, without using direct load measurements. Moreover, we also discuss different input measurements for our model as na alternative to the nacelle anemometer.

4. References

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NUMERICAL STUDY OF ROTATIONAL EFFECTS ON WIND TURBINES

Ivan Herraez, Bernhard Stoevesandt*, Joachim Peinke
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1. Introduction

The existence of rotational effects on rotating blades is known since nearly 70 years ago. Many efforts have been done for characterizing them and explaining their physics since their discovery by Himmelskamp [1]. Rotational effects are known to delay the point of stall onset and to increase the maximum lift. However, the origin of rotational effects is still poorly understood and the models that have been created for their characterization are rather unsatisfactory [2].

In the current work we aim at shedding some light on the phenomena of rotational effects by means of numerical simulations. The knowledge gained from the computations offers valuable information for the development of physically-sound correction models.

2. Results

The use of Reynolds Average Numerical Simulations (RANS) in conjunction with experimental results from the MEXICO turbine [3] is shown to be suitable for the study of rotational effects. The obtained numerical results are compared with surface pressure measurements and wake velocity fields from stereo particle image velocimetry (PIV) experiments. The agreement between simulations and experiments is in general satisfactory.

The lift coefficient (Cl) is observed to be enhanced at high angles of attack (AoA) in regions affected by rotational effects. However, the influence on the drag is almost negligible. The shape of the pressure coefficient (Cp) distributions in regions affected by rotational effects differs qualitatively from other wind turbines reported in the literature. Our results also show that the existence of rotational effects is closely related to the presence of radial flows on the boundary layer. Further, we show that radial flows are mainly caused by the centrifugal force acting on the separated volume of air. We conclude that the interaction between the centrifugal and the Coriolis forces lead to the enhancement of the lift force observed in rotating blades.

3. References

[1] Himmelskamp, H. Profile investigations on a rotating airscrew; Reports and translations, Völkenrode MAP, 1947.
[2] Breton, S.P.; Coton, F.N.; Moe, G. A study on rotational effects and different stall delay models using a prescribed wake vortex scheme and NREL phase VI experiment data. Wind Energy 2008, 11, 459–482.

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NEW INFRASTRUCTURE AND TEST PROCEDURES FOR ANALYZING THE EFFECTS OF WIND AND GRID LOADS ON THE LOCAL LOADS OF WIND TURBINE DRIVETRAIN COMPONENTS

Dipl.-Ing. D. Radner, Dipl.-Ing. C. Liewen, Dipl.-Ing. D. Bosse,
Dr.-Ing. R. Schelenz, Univ.-Prof. Dr.-Ing. G. Jacobs

In reality wind turbines are influenced by stochastic and unsteady wind loads. This results in high forces straining the wind turbines in all six degrees of freedom. Since the impact of the global deformations on system level on the local load situation cannot be described adequately with today's simulation models. Even for pure torque, local load distribution has to be verified on test benches from idling to overload. Today's simulation tools which consider the effects of the additional non torque loads on the drivetrain components behind the main bearing are nearly unvalidated. For a design optimization of wind turbine components with the aim of achieving a better load distribution, an optimal utilization of material, reduced costs and an increased availability, a better knowledge on the local loads conditions of all drivetrain components is required. As the local load conditions are affected by the wind loads, the grid loads and the operation behavior of the nacelle controller, new infrastructure and test procedures are required for measuring the local load conditions in the drivetrain. The new 4 MW wind turbine system test bench of the Center for Wind Power Drives is the world's first multi-MW test bench with a multiphysical Hardware in the Loop (HiL) operation mode, emulating a real six degree of freedom environment on wind side as well as a realistic electrical grid, in which the nacelle can operate using its original controller.
To emulate the wind loads in all six degree of freedom, the test bench consists of a 4 MW direct drive and a backlash-free non torque load unit (NTL). On the grid side a converter system controlled by a Real Time Digital Simulator (RTDS) with a step size of 2μs / 50μs emulates the behavior of the electrical grid for normal production and grid faults like voltage dips (Figure 1).

The presentation gives an overview on the functionality of the 4 MW wind turbine system test bench as well as the measurement results on the first device under test, a 3,3 MW wind turbine gearbox-generator combination type Winergy HybridDrive. Focus of the first measurement campaign is the identification of influences of the wind loads on the strains within the wind turbine gearbox on component part level down to the tooth root stress.

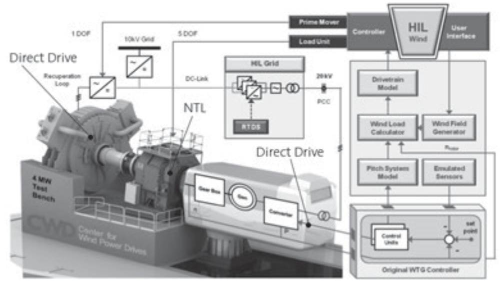

Fig. 1: 4 MW Test bench with its components and the HIL environment

CWD – Center for Wind Power Drives; c/o Institut für Maschinenelemente und Maschinengestaltung;
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DEWEK 2015

CFD ANALYSIS OF 10-MW WIND TURBINES

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1. Introduction

To maximise the amount of produced energy, wind turbine rotor diameters have increased during the last years, reaching values of 160m. Therefore, large scale wind turbines are operating at high Reynolds numbers and at high tip speeds, where compressibility effects begin to be important. It is the purpose of this paper to present results from CFD analyses of 10-MW wind turbines. For this, the Helicopter Multi-Block (HMB2) solver developed at Liverpool University [1] is used to estimate the aerodynamic forces. The HMB2 solver has so far been validated for several wind turbine cases, including the NREL Annex XX [2] and Mexico project [3] experiments. Two 10-MW wind turbines are used in this work, named InnWind [4] and AVATAR [5]. Their rotors have diameters of 178.3m and 205.8m, respectively.

2. Results

Steady and unsteady computations were preformed assuming rigid or elastic blades. The thrust and mechanical power as functions of wind speed are presented in Figure 1. Steady computations of the flows without the tower were conducted to establish this relation. For the rated wind speed and below, the CFD results agree reasonably with the design expectations (Figure 1(b)) and with the CFD results presented by [6] (Figure 1(a)). However, for the wind speeds above the nominal conditions the CFD tends to predict lower thrust and power production. This is due to the lack of pitch regulation at these calculations. For unsteady computations, the effect of the blades passing in front of the tower was captured. Results obtained so far, suggest the deficit in thrust around 31.76kN (2.11%) and in power around 386.98kW (3.87%) for the InnWind turbine. Detailed results are presented in the full paper.

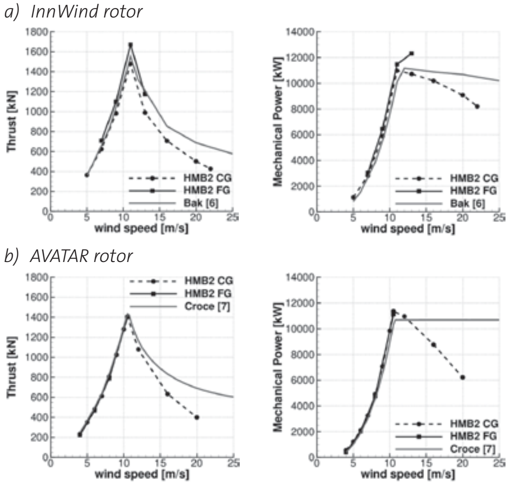

Fig.1 Thrust force and mechanical power as function of wind speed for the InnWind (a) and AVATAR (b) rotors. CG and FG – coarse and fine grid, respectively.

Acknowledgements

The financial support of the Marie Curie Host Fellowships Program: FP7-PEOPLE-2012-ITN-309395 - "MARE-WINT" and the European Energy Research Alliance project: FP7-ENERGY-2013-1/no. 608396 - "AVATAR" are gratefully acknowledged.

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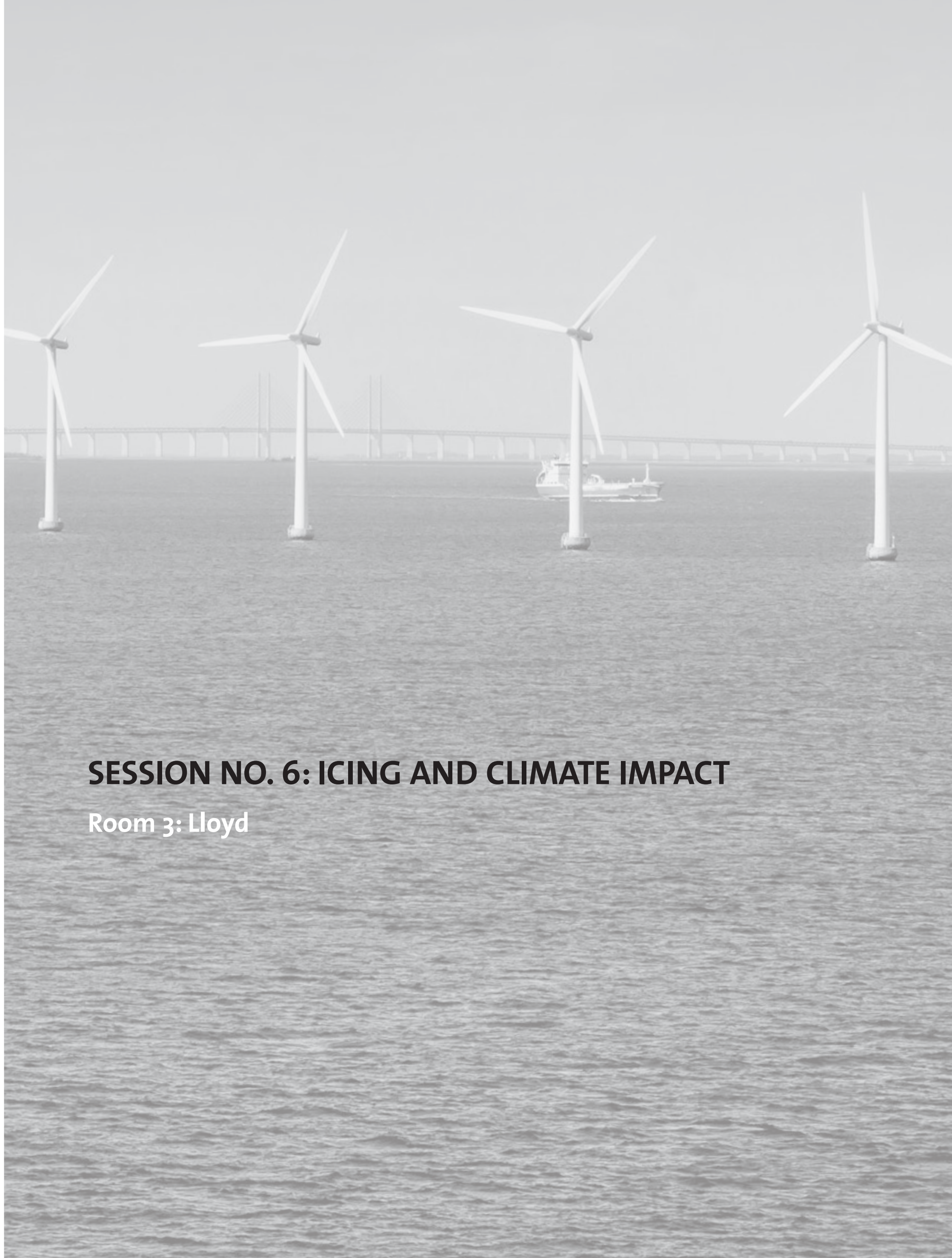

SESSION NO. 6: ICING AND CLIMATE IMPACT

Room 3: Lloyd

DEVELOPMENT OF ICE CLASSES FOR THE CERTIFICATION OF WIND TURBINES UNDER ICING CONDITIONS

Michael Steiniger[1], Kai Freudenreich[1], Xin Gu[2], Philipp Thomas[2], Ville Lehtomäki[3]

1. Introduction

Areas like Scandinavia, North America and northern Asia as well as areas with high altitude feature a high potential for large capacity wind farms thanks to favourable wind conditions and mostly low populated areas. Estimations state that the wind energy potential for icing climate is larger than that for offshore.
In icing conditions, the turbine can suffer from increased loading due to mass and aerodynamic imbalances, while the changed aerodynamics of iced blades can lead to severe energy losses.
Present international guidelines and standards [1], [2], [3] consider icing effects for design and certification to some extent. However, further development of guidelines and standards is required, in order to consider icing also for modern multi-megawatt-size wind turbines. The presently applied icing models rely mostly on kilowatt-size wind turbines, so far the influence of ice on the blade aerodynamics is neglected.
A consortium among research and test institutes, wind turbine manufacturers and certification bodies has started the international research project IcedBlades to increase the knowledge and to improve the wind energy reliability in cold and icing climate conditions [4].

2. Objectives

This publication intends to describe the definition of ice classes for wind turbines and their connection to site ice assessment measurements with respect to
– duration of ice accretion on the blades
– the intensity of ice accretion
– the resulting mass and aerodynamic effects.

The defined ice classes will be used to modify the wind turbine models being used for aeroelastic simulations in order to calculate the mechanical loads as well as the power performance of the wind turbines.

3. Approach

The load calculations presented in this publication is based on a 2.5 MW horizontal axis wind turbine model, which is simulated with fully coupled aeroelastic code in the time domain. The airfoil polar data and blade ice mass are calculated according to various ice classes.

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DURABLE HYDROPHOBIC COATINGS FOR ICING PROTECTION OF WIND ENERGY PLANT

Dr. Katrin Lummer[1], Nadine Rehfeld[2], Dr. Volkmar Stenzel[3]

1. Introduction

1.1 Icing on wind energy plants
The formation of ice on the wings of wind energy plants has negative effects on the energy output. The change of the aero dynamical profile leads to a loss of performance and the shutdown of the plant for safety reasons. Remedy can be found in the use of heating systems and hydrophobic coatings [1].

2. Anti-icing solutions

2.1 Coating concepts

New coating concepts for the reduction of ice-accretion and ice adhesion and new testing strategies of the anti-ice-function are presented. Regarding the coatings, different approaches can be considered. Isolation of the substrate reduces the amount of energy needed for the heating system significantly. Also advantageous is the ability of a coating to repel water drops (Figure 1).
These hydrophobic coatings avoid ice being formed on the surface or avoid ice adhesion for the easier and less energy demanding removing of the ice. The layer composition has to fulfil certain requirements, especially the resistance to the frequent temperature change to avoid a loss of functionality caused by the delamination of the coating. Additionally, all standard properties such as hardness, weather and erosion resistance, flexibility and optical demands have to be combined in the coating. The durability of hydrophobic coatings is a challenging research topic

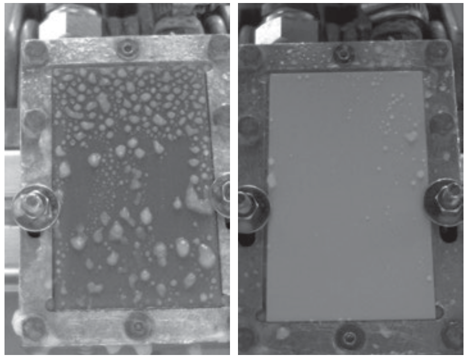

Fig. 1 left: unmodified coating, right: hydrophobic, water repellent coating

2.2 Testing strategies

For testing of anti-ice-systems under realistic conditions, extensive and specialized test plants are necessary. These have to consider the relevant conditions of wind energy plants, including wind speed, temperature and humidity. Also the formation of undercooled water droplets for the simulation of icing scenarios is important for a realistic evaluation of the anti-ice-function. The Fraunhofer IFAM holds an ice chamber for the operation of rime tests and ice rain tests and a novel ice-channel for realistic ice-tests on rotor blades the testing of icing sensors and anemometers (Figure 2).

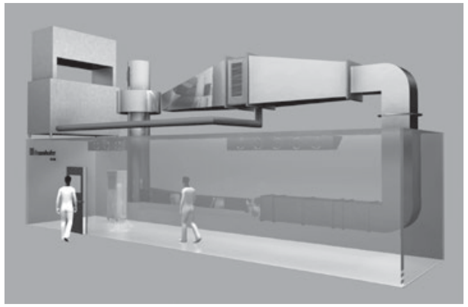

Fig. 2: Ice-channel

3. References

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PERFORMANCE OF AN ENERCON WIND TURBINES UNDER ICING CONDITIONS IN EUROPE

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1. Introduction

Atmospheric icing has a significant impact on the development and the operation of wind parks. It causes production losses and represents a safety risk for passersby and service personnel. Still, there is an emerging market for wind energy projects in cold climate. At the same time, sinking electricity prices increase the pressure on existing projects to maximize the production in order to stay profitable. In this context, the performance and the efficiency of a de-icing system is a central aspect for a successful wind park.

During winter 2012/13 and 2013/14, ENERCON wind turbines equipped with a rotor blade heating in several wind parks in Europa were monitored in order to evaluate their performance under icing conditions. The wind parks were located in Switzerland, Czech Republic, Germany and Sweden. The wind turbines were equipped with one camera pointing at nacelle and two cameras pointing at the blades. Furthermore, the operational data of the wind turbines was examined.

2. Evaluation

In a first step, the icing conditions at the sites were analysed. Based on a classification of camera images, the IEA ice class of each site was identified. Furthermore, the periods of meteorological icing were subdivided in three classes of icing intensity and the instrumental icing in five classes of ice loads. This allowed for a more detailed interpretation and comparison of the different icing climates at the test sites. Finally, the typical wind conditions (wind speed and wind direction) during icing events were studied.

In a second step, the performance of the blade heating was examined in general with regard to the icing conditions and in selected case studies. The rotor blade heating of the different wind turbines were operated in various operational modes within the same wind park. This allowed for a detailed comparison of the performance of different heating strategies during icing events and a quantification of the overall icing losses with regard to the site-specific icing climate.

3. Results

The analysis showed that the ENERCON rotor blade heating significantly increases the energy production under icing conditions. The performance of the rotor blade heating system strongly depends on ice load and icing intensity. The performance is good for light to moderate ice load and intensity classes but decreases for events with high ice loads and severe icing intensity. These situations are not very frequent, but still impact the total energy yield loss.

This result also shows that the local icing conditions (ice loads and icing intensities) need to be known in detail in order to estimate related energy yield losses in a proper way.

DEVELOPMENT OF AN RAIN AND PARTICLE EROSION TEST SCENARIO TO ENHANCING THE ROTOR BLADE PERFORMANCE AND DURABILITY

J. Liersch[1], J. Michael[2], M. Mühlbauer[3], P. U. Thamsen[4]

1. Introduction

1.1 Erosion-induced changes on blades

During their operational life span of around 20 years, the individual components of a wind turbine, especially the rotor blades, are exposed to extreme environmental influences. These effects result in leading edge erosion.

That erosion has serious impacts on the rotor performance has been shown previously by Sareen et al. [1] where an increase in drag coefficient by 80-200% was observed. Additionally, a decrease in lift coefficient for higher AOA was ascertained. The results implied a significant loss in AEP by 7% for an increased drag coefficient of 80%.

1.2 Erosion mechanism

The damage mechanism due to droplet impingement is based on enduring loads from individual impacts. The stress duration of an individual impact amounts to just a few milliseconds [2]. According to [3], the surface damage is induced by high pressure and the formation of a lateral jet that occurs at the burst of a droplet.

Particle erosion as a form of jet abrasion depends on fracture processes [4]. The four basic mechanisms that lead to particle erosion are abrasion, surface fatigue, plastic deformation and brittle fracture [5].

2. Test chamber and testing conditions

2.1 Rain and particle erosion tests

We intend to build a test facility with a rotating arm that can carry two specimens at once (Fig. 2) and that is equipped with a recirculation for water and particle mass flows.

The test scenarios are based on real weather conditions of wind turbine sites and include rain droplet as well as a particle application. The upcoming tests will serve as a basis for consistent testing to provide comparable findings for customers and manufacturers.

This work is supported by the German Federal Ministry of Economics and Technology. (grant no.: KF3167502DF3)

Fig. 1: Erosion test chamber

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INFLUENCE OF WIND CONDITIONS UNDER ICING CONDITIONS ON THE RESULT OF A RISK ASSESSMENT

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The increasing use of wind turbines in Germany has shown that open areas for the installation of wind turbines are increasingly difficult to find. Particularly if the wind turbines are very close to residential areas, industrial areas or traffic infrastructure, the operation of wind turbines may cause hazards that should be assessed. Especially in winter it increases the risk that people can be hit and objects can be damaged by ice fall and ice throw. So if minimum distances to objects at risk cannot observed, risk assessments have to be performed.

The risks for persons and protection objects and the radius of falling ice depends on the site-specific wind conditions, like the distribution of wind direction and wind speed as well as on the distance of the objects to the wind turbine. Therefore it is necessary to determine the wind conditions under icing conditions as accurately as possible to identify the risk as precisely as possible.

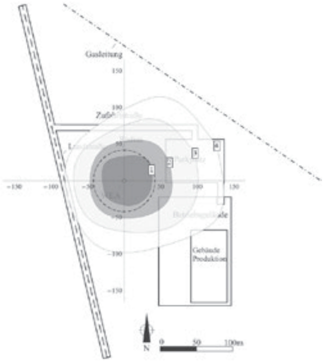

Fig. 2: Case Study: Risk areas for a site with particular wind conditions (Source: TÜV NORD 2014)

Particularly the wind conditions should be analysed very carefully because wind statistics based on long-term data could be totally different to those based on data for icing events.

On basis of climatic field data, wind statistics (wind direction, wind speed) were analysed for condition of icing events as well as on climate statistics (temperature, humidity). These wind statistics were compared to wind statistics based on long-term data. Furthermore the data were used within a risk assessment (fictitious case study).

Fig. 1: Iced wind turbine (Source: iea 2009: (Photo: Kent Larsson))

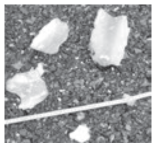

Fig. 3: Ice objects (Source: Meteotest 2007)

Therefore the data of 30 different weather observation stations in Germany were analyzed and three different scenarios were developed:

1. For the long-term data (the whole dataset of the weather station),
2. for climatic icing conditions (0,5 °C and 95% relative humidity based on different literature [1], [2]) and
3. for conditions of icing events (icing has been observed at the observation site).

The results show that, the weibull distributions of the two icing scenarios are more pointed in a lower wind speed range. The mean wind speed is generally lower. Also the frequency distributions are different in the three scenarios.

Due to the higher mean wind speeds of the annual climatic data, the simulated icefalls in the fictitious case study for the risk assessment achieve a greater range resulting in larger risk areas. Additionally, the frequency distribution of the wind direction can change significantly under icing conditions, and a difference in the hit frequency could be determined. That affects different shapes of the risk area.

The use of the annual climate data for the risk assessment proved as conservative in the case study but by considering the wind conditions under icing conditions/icing events, a precise delimitation of the risk areas could be achieved.

Further this is not only important for the evaluation of the possible risks but for a accurate prognosis of the annual energy yield, e.g. it could be crucial for the economic feasibility of a wind farm planned at an exposed "icing-risk" site.

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DEWEK 2015

SESSION NO. 8: OFFSHORE FOUNDATIONS

Room 2: Kaisen Saal

INFLUENCE OF THE LOADING FREQUENCY ON THE FATIGUE PERFORMANCE OF SUBMERGED SMALL-SCALE GROUTED JOINTS

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1. Motivation

Within the next 15 years, the German government intends to expand the electricity production from German offshore wind farms to an amount of 15 GW of electrical energy. This corresponds roughly to an erection of 3000 new offshore wind turbines (OWT). Most of these will be located far from shore in water depths deeper than 30 m. For such water depths, lattice substructures like jackets are the preferred solution (cf. Figure 1). The substructures are founded on piles and connected to the piles via submerged grouted joints. Even though, the grouted joint is well known from the offshore oil & gas industry, only few results on the effects of water on the connection's fatigue performance exist.

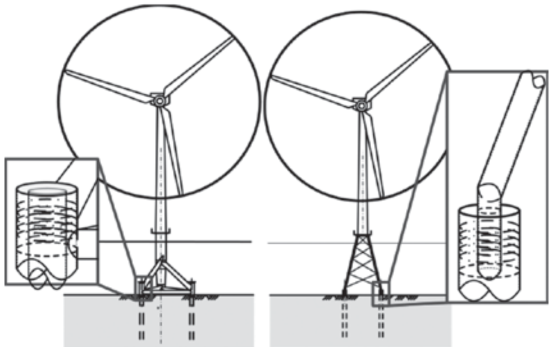

Fig. 1: Grouted joints in tripod (left) and jacket (right) substructures for OWTs [1]

2. Investigations and Results

At the Institute for Steel Construction, Leibniz University Hannover, Germany within the joint research project "GROWup" investigations focus on the fatigue performance of grouted joints under predominant axial loading. The project is funded by the Federal Ministry for Economic Affairs and Energy (BMWi, funding sign: 0325290) and is the third project in a row dealing with grouted joints. As part of this research project, fatigue tests on small-scale grouted joints with shear keys are conducted. The specimens are filled with an industrial grout product and tests are executed in a water basin to investigate the influence of water on the fatigue performance of the connection.

First published test results [1] showed that water significantly reduces the fatigue performance of the connection by up to 1/10 compared to results from tests under dry conditions. Moreover, the impact of water is proportional to the applied loading frequency and decreases with lower frequencies. Based on these first results, a systematic approach for testing small-scale grouted joints with varied loading frequency was developed and conducted.

This paper presents the systematic testing approach as well as test results from 15 small-scale tests on submerged grouted joints with different loading frequencies. All test results are evaluated according to the systematic approach. In addition, an engineering approach to consider the influence of the frequency on the fatigue performance is proposed.

3. References

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NOVEL TEST FACILITIES FOR GROUTED CONNECTIONS

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1. Experimental simulation of filling procedures for grouted joints

Grouted Joints are typical connections between pile and substructure of offshore wind turbines. A sleeve is plugged over the pile and the resulting gap between the tubes is later filled with a high-performance grout. The filling process has to be done under offshore conditions.
Laboratory scaled filling tests have shown different material properties compared to standard test samples. A reduced compressive strength under submerged conditions was partly observed. Further tests have shown diverse compressive strength zones at test-specimens of filling tests [1,2]. Also certification bodies expect different in-situ material properties in grouted joints. Therefore GL-DNV attenuates the compressive strength of the grout [3].

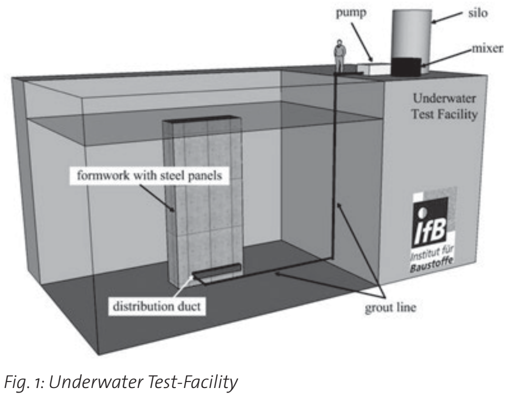

Fig. 1: Underwater Test-Facility

2. Large Scale Test-facilities

The Large Scale Test-Facility (LSTF) was developed for nearly real-scaled filling tests to estimate in-situ material properties and to observe phenomenas of the filling process. The formwork of the test facility is about 3.75 m high, the length is about 3.3 m and the size of the gap is flexible from 5 cm up to 20 cm. It is possible to fill the gap with water to simulate the filling process of submerged grouted joints e.g. jacket substructures. The Underwater Test-Facility (UTF) is the most realistic test- facility for filling tests up to now (Fig.1). The formwork is completely submerged with a max. length of 7.2 m and with a max. height up to 8.1 m. Steel is used for the formwork panels including shear keys to simulate most realistic conditions. This paper will present results from filling tests with the LSTF and presents the potential of the UTF.

3. Early-Age Cycling Test-facility

The developed test-facility represents a new method to evaluate different grout materials and its performance under early-age cycling loadings. First results showed a possible adverse influence of cyclic loadings on the properties of hardened grout materials resulting in a reduced compressive strength. However, the investigations also represent grout materials with a good performance and thereby only a minor influence of early-age movements [4].

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OFFSHORE PILE DESIGN IN THE LIGHT OF TEST RESULTS

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1. Axially loaded OWEC piles

Offshore piles have to withstand predominantly cyclic axial loads when they are installed in multi-pile configurations, as in jacket foundations (Fig.1). From the geotechnical perspective the dimensions of the piles are ruled by the external capacity in the pile-soil interaction. While a large number of pile foundations is required for the current and future installation of offshore wind-farms, crucial questions on the pile design are still discussed controversially. Concerning the pile capacity, two major topics of research are the determination of possible capacity gains due to pile ageing effects. Secondly, repeated cyclic loading is supposed to affect the load capacity of the pile and increased deformations have to be checked for serviceability.

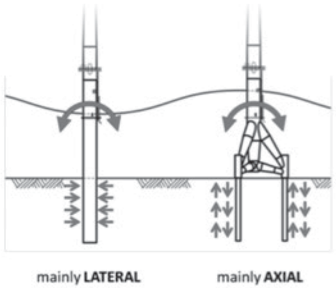

Fig. 1: Monopile (left) and Multi-pile (right)

New input is gained from the amount of data available from recent pile testing during pile installation in the German bight. Furthermore, large scale field tests have been carried out and older experiments have been reconsidered to better understand the influence of ageing and cyclic loading on the pile capacity [1-3].
In order to investigate both effects, a large scale testing facility has been constructed at the BAM TTS site. In this open-air facility, large driven pipe piles can be loaded cyclically in both tension and compression, while the ageing effects can be studied by introducing temporal delays between the testing campaigns.
In this paper test results are presented and discussed with respect to its impact on pile bearing behaviour. Aspects of predesign and its verification are considered. The findings on pile set-up behaviour are evaluated. Special emphasis is put onto capacity reduction and failure of cyclically loaded piles. All aspects are discussed with respect to current design procedures and approval demands.

Fig. 2: Pile Test Site at BAM Horstwalde

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MONOPOD BUCKET FOUNDATIONS UNDER LATERAL CYCLIC LOADING

Aligi Foglia*, Lars Bo Ibsen**

1. Introduction

To enable a prosperous development of offshore wind energy, economically feasible technologies must be developed. According to the specifics of each offshore wind farm, the costs of construction and installation of sub-structures fluctuate between 20% and 30% of the total investment cost.

The monopod bucket foundation (cf. Figure 1) is likely to become a cost-effective sub-structure for offshore wind turbines and has the potential to make offshore wind more cost-competitive in the energy market. To enable a fully optimized design of bucket foundations for offshore wind turbines (OWTs), some aspects of their behaviour are still to be understood.

Fig. 1: Full scale bucket foundation on the deck of a jackup vessel

The article presents the main achievements of the physical and numerical investigations on bucket foundations under lateral cyclic loading conducted at Aalborg University between 2011 and 2014. In particular, the research work aims at extending the knowledge regarding monopod bucket foundations under long-term lateral cyclic loading.

2. Methods

A comprehensive experimental campaign including 64 tests of three bucket foundations with diameter equal to 30 cm and length of the skirt equal to 30 cm, 22.5 cm and 15 cm, respectively, was carried out. The experimental data was interpreted with an empirical model. Furthermore, a numerical model was developed on the basis of the experiments. The numerical model combines a standard macro-element model and a boundary surface model.

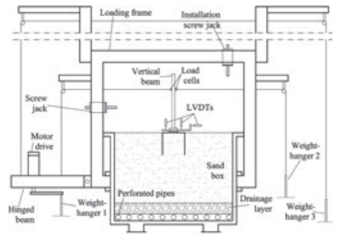

Fig. 2: Sketch of the experimental rig

3. Results

The analysis of the experiments reveals that the parameters of the empirical model are not influenced by the length of the skirt. Besides, the post-cyclic capacity exceeds the standard monotonic capacity. The numerical model is calibrated with the experimental data. A retrospective analysis of the small-scale tests shows satisfying prediction abilities of the numerical model both in terms of monotonic and cyclic loading. The physical observations and the numerical interpretation are regarded to be significant steps forward in the modelling of bucket foundations for OWTs under long-term cyclic lateral loading.

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NUMERICAL SIMULATION OF CYCLIC HORIZONTALLY LOADED PILES UNDER SPECIAL LOADING CONDITIONS

Albiker, J.[1], Achmus, M.[2], Thieken, K.[3]

With the help of the so called Stiffness Degradation Method (SDM, [1]), the behavior of cyclic horizontally loaded piles can be modelled by means of numerical simulations including regression parameters determined in cyclic triaxial tests. Results are presented that exhibit the use of the method for non standard loading conditions, i.e. on the one hand one-way loading without full unloading after each cycle and on the other hand modelling of very low load levels, where due to the elastic character of deformations the soil behaves stiffer than commonly assumed, by coupling the SDM to a special “Small Strain Stiffness” approach.

1. Introduction

The principle idea of the SDM is that the decrease in stiffness E over the number of cycles of a test specimen in a cyclic triaxial test or of a soil element in a pile soil system is determined after the equation:

$$E_N = E_1 \cdot N^{b_1 X^{b_2}}$$

X corresponds to the load level and b1 and b2 are regression parameters to be determined in a cyclic triaxial test. With known values for these parameters, the above equation is used to simulate the behavior of the soil elements of a pile soil system. The method is regularly used for simulating swell load with full unloading after each cycle.

2. Simulation of non standard swell load

A decisive parameter in a cyclic triaxial test is the relation between minimum and maximum applied stress in a cycle, denoted by the parameter $\zeta_c = \sigma_{min}/\sigma_{max}$. For swell load with full unloading, ζ_c equals 0. If no full unloading occurs, ζc gets positive values and tends towards 1.0 for a “quasi static” test. For the presented work, cyclic triaxial tests were carried out at different cyclic stress conditions and varying load levels X. From the resulting strain progress over the number of cycles, values for b_1 and b_2 were determined. As visualized in Fig. 1, a clear dependency of the resulting values of ζ_c is observed. From fitting curves, furthermore an ascending tendency of the deformation accumulation with the load level can be obtained. The resulting parameter values are finally used for modelling an exemplary pile soil system with the SDM.

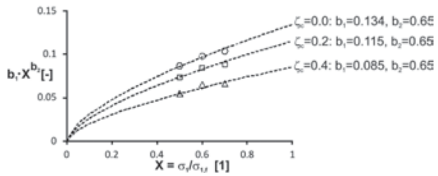

Fig. 1: Regression values from cyclic triaxial tests

3. Simulation of low load level

By coupling the SDM to the Small Strain Stiffness approach after [2], the cyclic pile deformation behavior at very low load levels is investigated. The results show a reduced cyclic deformation accumulation. The characteristics and the intensity of reduction are dependent on the pile soil system stiffness.

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SESSION NO. 9: SIMULATION TURBINE CONTROL

Room 3: Lloyd

NUMERICAL MODELLING FOR OPTIMIZATION OF WIND FARM TURBINE PERFORMANCE

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1. Introduction

Wind power generation is challenging because of the stochastic structure of winds which makes it difficult to predict it at any specific point in space and time. So, management of wind farms becomes complex compared with geothermal and hydroelectric power plants [1]. Balancing supply & demand & integrating wind energy into a power distribution system's grid demands accurate forecasting tools to predict the timing & strength of wind power ramps. Effective and efficient management feeds into attractive market price incentives [2].
It is therefore beneficial to apply research effort to refine modelling approaches that accurately represent detailed topography, that properly account for regional forcing field, are cost effective, have real time data assimilation for locally acquired data & that permit downscaling of the physical processes as the spatial resolution is reduced. Our current research direction couples the outputs of a mesoscale model (WRF) with a micro-scale CFD model (OpenFOAM) & includes constraining model outputs by ingesting three dimensional wind observations from Coherent Doppler LIDAR (CDL).

2. Methodology

This research follows a physical approach for achieving accurate wind forecasts for a particular wind farm. The steps in this workflow are:

a. Coupling optimised WRF model with OpenFOAM for prediction of micro-scale wind for improving turbine energy output estimation.
b. Assimilating CDL radial velocity measurements into WRF-CFD for constraining & improving fidelity in resolving localized winds.
c. Evaluating impact using comparisons with in situ meteorological measurements.

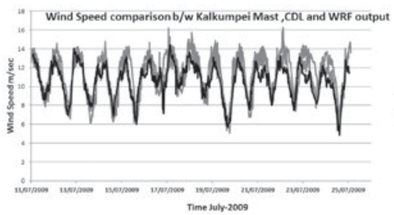

Figure 1 Wind speed comparison b/w mast A, WRF output and Coherent Doppler LIDAR (CDL) at 39 m height

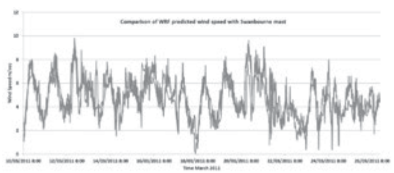

Figure 2 Comparison of wind speeds for meteorological station and WRF predicted wind at 10m height

2. Research Outcomes

The WRF model has been evaluated with initialisation fields from two different sources and optimised using different grid configurations, with several choices of physical and parameterization schemes. Consequently, the RMSE errors for predicted versus in situ mast-measured winds [masts designated as A, B and C] are 1.6, 1.7 & 1.9 m/sec & correlation coefficients (CC) are 0.69, 0.57 & 0.48 respectively. The wind direction RMSE for mast A & B are 12.01° & 13.23° & CCs are 0.44 & 0.24 respectively – see fig 1.These results are validated with CDL measured wind speed where wind speed RMSE and CC between mast and CDL are 0.93 and 0.9 respectively. WRF's performance initially was validated in a well-defined coastal meteorological environment with wind speed RMSE 1.27 m/sec, CC 0.70 & wind direction RMSE was 32° & CC was 0.78 (fig 2). In addition, a spatial verification of the WRF model outputs with that of CDL has been performed at turbine locations. The final step of using WRF outputs as inputs to OpenFOAM and validation via CDL is in progress.

3. References

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MULTIVARIABLE MODEL FOR SIMULATION AND CONTROL DESIGN OF WIND TURBINES

Bastian Ritter* **, Holger Fürst**, Ulrich Konigorski* **, Mike Eichhorn***

1. Introduction

Multivariable approach for control design of wind turbines provides new strategies to reduce mechanical loads and thus optimize operation and lifetime. Using Lagrange's Equations, an analytical state space model is developed which incorporates the significant degrees-of-freedom of horizontal axis wind turbines (HAWT). The model is used for simulation of system dynamics, for system analysis as well as for designing and testing of multivariable controllers. First simulation results and controller's design are presented based on a virtual 5-MW turbine model defined by Jonkman et al. [1].

1.1 Modelling System Dynamics

To optimize lifetime of wind turbine components systematically it is necessary to model system dynamics appropriately. A valid physical model predicts system behaviour and mechanical loads on rotor and tower.

1.2 Influence of Controller

Wind turbines are autonomous acting systems which cannot operate without supervisory control and safety systems. However, the actual wind turbine controller has a major effect on mechanical loads. This fact allows for reducing load peaks smartly by control. Though, an analytical insight into system dynamics is inevitable.

2. Derivation of Analytical Model

As stated before a mechanical model, incorporating blade and tower deflections, is derived using Lagrangian Equations [2]. Secondly, an aerodynamic model is presented based on BEM theory [3] to obtain forces on single blades and tower. These two models combined yield the controlled multivariable system with generator torque and individual blade pitch angles as command inputs (Fig. 1).

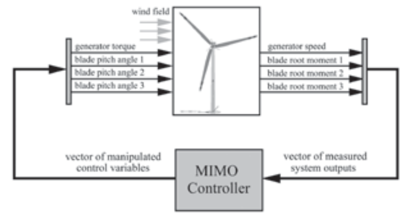

Fig. 1 Closed loop control system

2.1 Simulation

Results from numerical simulation comparing the analytical approach with nonlinear aeroelastic codes like FAST [4] show good agreement. Therefore, the analytical model with physical insight is employed for control design.

2.2 Use for Multivariable Control Design

Typically, wind turbine control circuits are several independently designed systems besides existing coupling between them. Thus, controller performance may not as good as it could be. By deploying a centrally designed multivariable controller this issue can be resolved. Simulation results using a state-feedback controller show a good performance with respect to power production and load mitigation. In future, this model will be refined to gather further couplings and then used as internal model to investigate the model predictive control (MPC) for wind turbines.

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NUMERICAL INVESTIGATION OF WAKE DEVELOPMENT IN A STABLE ATMOSPHERIC BOUNDARY LAYER

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Summary

Detailed knowledge about the flow in wind farms is of great interest for potential energy cost reduction by power production optimisation. An aeroelastic and a large-eddy code were therefore coupled to investigate the development of wake structures in wind farms under the influence of various atmospheric conditions and turbine control concepts.

1. Introduction

During the design but especially during the operation of a wind farm it is necessary to consider the mutual aerodynamic influence of turbines. Wake flow conditions can lead to substantial losses in the energy yield as well as an increase in structural loads due to larger inhomogeneity in the wind field and higher turbulence. Advanced wind farm control concepts (e.g. wake deflection), focusing on the mitigation of these effects, are therefore of growing interest. Nevertheless a better understanding of the flow development in a wind farm and the wind turbine – flow interaction under the influence of various atmospheric conditions and turbine control concepts is of fundamental importance for a successful industrial application.

2. Methods/Results

The developed code couples the LES flow solver PALM [1] and the aeroelastic wind turbine simulation tool FAST [2] based on the actuator line (ACL) approach.

It performs on parallel computer architectures and combines the entire turbine modeling capabilities of FAST with realistic inflow conditions for the simulation of arbitrary wind farm layouts and turbine setups. Therefore the results could help support the verification and development of simplified and computationally less expensive wake models (see Fig. 1), which are suited for the application in advanced control methods. Simulation results will be presented focussing on the interaction of multiple wakes at various turbine setups and inflow conditions (see Fig. 2).

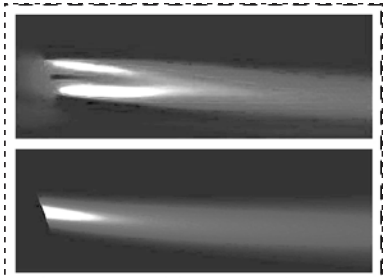

Fig. 1: Wake deflection caused by 20° yaw (code coupling and engineering model)

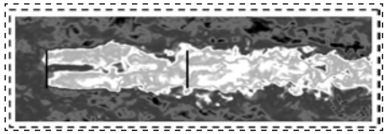

Fig. 2: Interaction of two wakes (NREL 5MW, u_{hub} = 10 m/s, TI = 6.5%)

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This work was partially funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) in the scope of the CompactWind project (FKZ:0325492B).

CORRELATION-MODEL OF ROTOR-EFFECTIVE WIND SHEARS AND WIND SPEED FOR LIDAR-BASED INDIVIDUAL PITCH CONTROL

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Introduction

For the purpose of optimizing scan trajectories of nacelle-based lidar systems as well as the a-priori configuration of the filter needed for a lidar-assisted feed-forward controller, a spectra based model of the correlation between lidar systems and wind turbines has been presented in [1]. Since this model accounts only for the rotor-effective wind speed, it is extended in this work to include also the linear horizontal and vertical shears with regard to the application of future lidar-assisted individual pitch controllers. Finally, the results achieved with this extension and their validation in simulation is shown.

1. Methodology

1.1 Correlation-Model

The knowledge of the correlation between the rotor-effective wind speed measured by a lidar system and the one experienced by the turbine is important for lidar-assisted control. The general idea of the correlation model is to avoid time consuming simulations in the time-domain. Therefore, the model calculates the correlation directly from the spectral properties of a wind field as shown in Figure 1. This is achieved by a transformation of the equations for the lidar measurement and the wind reconstruction into the frequency domain.

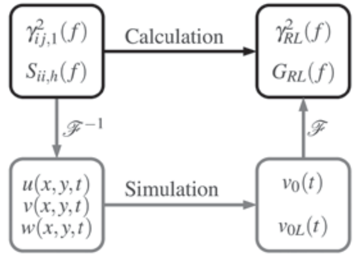

Fig. 1: Basic idea of the correlation model.

1.2 Extension to Linear Shears

By the implementation of a different wind field reconstruction algorithm which solves a least-square-problem in order to reconstruct not only wind speed but also the linear horizontal and vertical shears from the lidar measurements based on [2], the model is extended to three wind characteristics. This enables the model to be applied for individual pitch control.

2. Results

2.1 Trajectory Optimization

The model is used to optimize lidar scan trajectories by means of an optimization with regard to the coherence bandwidth of the three wind characteristics. It is shown that for the reconstruction of the shears different scan patterns are beneficial than for the reconstruction of the wind speed only. This adds a new dimension to the optimization problem.

2.2 Validation in Simulation

Additionally, it is shown in simulation that with the optimized scan trajectories one gains the predicted correlation. This validates the extension of the correlation-model and demonstrates the model's benefit for the design of lidar-based individual pitch controllers.

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COLLABORATIVE RESEARCH ON WIND TURBINE LOAD CONTROL UNDER REALISTIC TURBULENT INFLOW CONDITIONS

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G. Kampers, M. Hölling, J. Peinke **
A. Fischer, T. Lutz, E. Krämer ***
U. Cordes, K. Hufnagel, K. Schiffmann, H. Spiegelberg, C. Tropea ****

1. Introduction

Modern turbines control load and power by actively adjusting the angle of attack via pitch variation. However, this technology is not suited for compensating the inflow variations generated by the atmospheric boundary layer or from upstream wind turbines (wind farms) or yaw errors, sudden gusts or turbulence which can occur within seconds or less and can have local impact on a rotor blade.

In a collaborative research effort of five German universities, passive and active flow control methods for the alleviation of dynamic loads, load fluctuations and for reduction of wake effects are investigated, both experimentally and numerically.

Furthermore, numerical tools suitable for evaluating the overall cost reduction and benefit of flow control methods on wind turbines will be validated and extended such that the results can be transferred to full-scale wind turbines under realistic inflow conditions.

2. Approach

The project is funded by the DFG and realized through six strongly interacting sub-projects:

- P1: Development of an aeroelastic simulator suitable for evaluating the overall cost reduction and benefit of flow control methods on real size wind turbines [1].
- P2: Experimental assessment of active flow control techniques for wind turbines with a research turbine in a wind tunnel.
- P3: Numerical verification of passive and active load alleviation techniques for wind turbines in atmospheric turbulence.
- P4: Analysis of active control of wind turbine wakes using zonal LES.
- P5: Passive Flow Control on Wind Turbine Rotors Using Self-Adaptive Camber.
- P6: Generation of turbulent wind fields by an active grid and stochastic analysis of the force dynamics on 2D wind turbine airfoils with active flow control.

Fig. 1: Wake simulation in project P1

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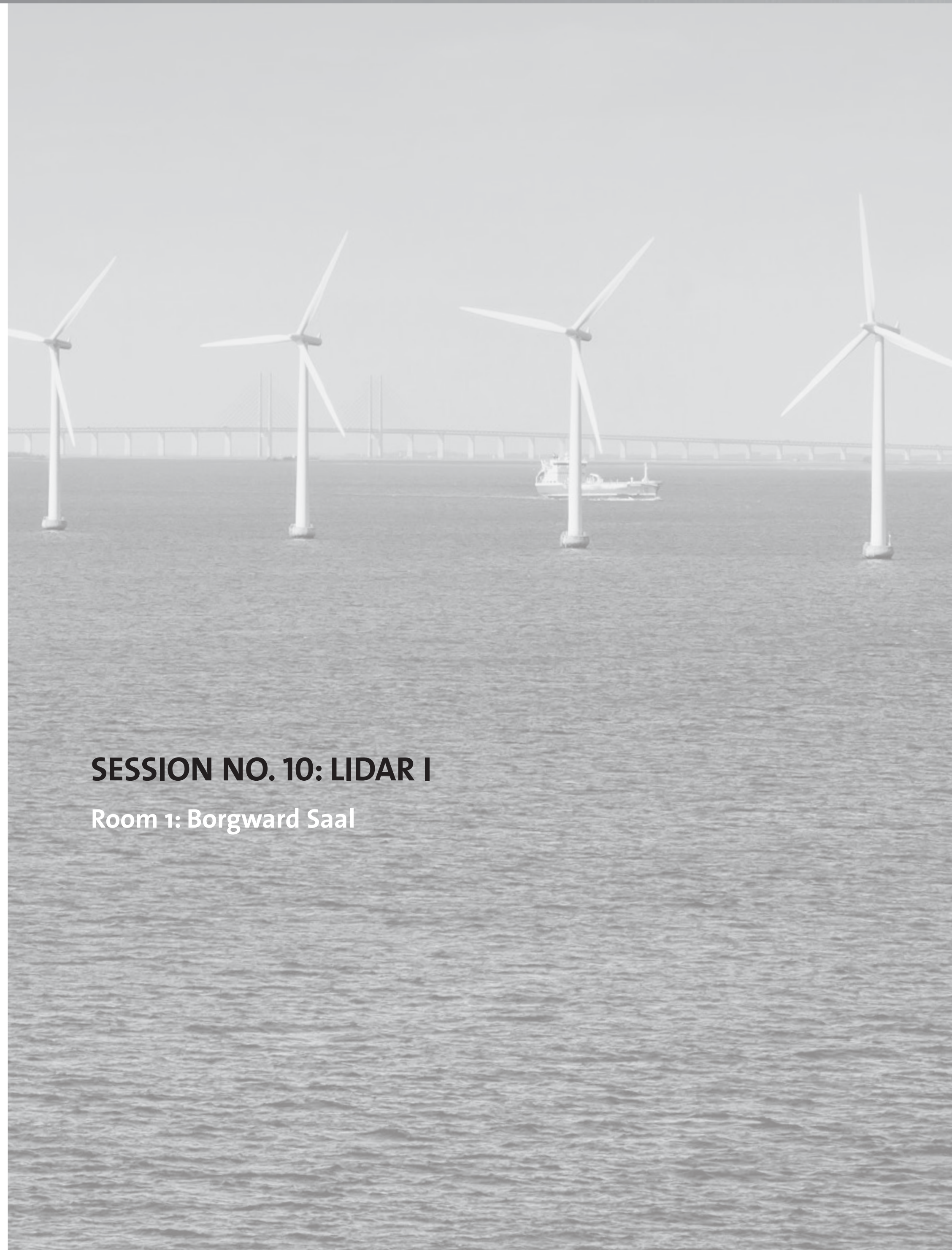
DEWEK 2015



SESSION NO. 10: LIDAR I

Room 1: Borgward Saal

"GW WAKES": MEASUREMENTS OF WAKE EFFECTS IN »ALPHA VENTUS« WITH SYNCHRONISED LONG-RANGE LIDAR WINDSCANNERS

J. Schneemann[1]*, D. Bastine[1], H. Beck[1], M. v. Dooren[1], J. Schmidt[2], G. Steinfeld[1], D. Trabucchi[1], J. J. Trujillo[1], M. Kühn[1]

The flow conditions in the planned very large offshore wind farms with hundreds of multi-megawatt wind turbines sited in wind farm clusters will differ in various aspects significantly from what is presently known on wake effects of small to medium-scale wind farms. This contribution will provide an overview on the results of the joint research project "GW Wakes – Analysis of wake effects and wake turbulence characteristics of large offshore wind farms by comparison of »alpha ventus« and »Riffgat«" gathered during the first measurement campaign in »alpha ventus« with two scanning lidars on »Fino1« and one lidar on the »alpha ventus« substation conducted from summer 2013 till spring 2014.

First an overview on the preparation, planning, conduction and encountered challenges of the offshore measurement campaign in »alpha ventus« is given.
A method to calculate the 2D horizontal wind field from the scans of two different lidars was developed (Figure 1).

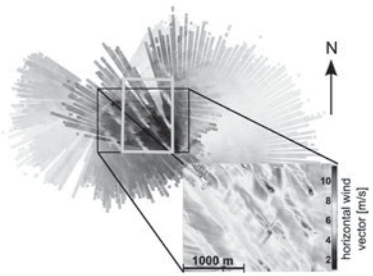


Fig. 1: In the background two azimuthal scans performed with long range lidars based on the substation in »alpha ventus« (marked by green box) and »Fino1« are visualized. The highlighted section shows the horizontal component of the farm flow calculated from the two scans. Wakes of three rows of turbines are clearly visible.

Another focal point of the project is the measurement, characterization and modelling of the turbulent flow within offshore wind farms, especially in the case of multiple overlapped wind turbine wakes. Proper orthogonal decomposition analysis (POD) of LES data was used to show that a wake can be partially described by the superposition of only a few spatial modes. Combined with a stochastic model for the temporal evolution, such a reduced description is the basis for the development of a new kind of simplified dynamic wake models.
The wake of a wind turbine was analysed in the frequency domain using staring lidar measurements, showing a peculiar signature at the interface between wake and free stream. Another method used on this data showed the distinct statistical behaviour of different wake regions. In the center of the wake the dominant length scales of the turbulent flow were found to be much shorter than outside the wake region.
High resolved LES (Large Eddy Simulations) and meso-scale models are used to simulate and validate the inner wind farm flow and the wake of the whole wind farm. Both are compared with lidar measurements. Finally the technology transfer will be assured by implementing turbulence characteristics as well as shadowing effects into engineering models. Therefore the new software FlapFOAM was developed.

The project "GW Wakes" is funded by the Federal Ministry for Economic Affairs and Energy (FKZ 0325397A-B).

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ANALYSIS OF WAKE SWEEPING EFFECTS BASED ON LOAD AND LONG-RANGE LIDAR MEASUREMENTS

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1. Introduction

Wind turbines operating in wake are affected by an inhomogeneous wind field. In this paper full-field measurements are compared to two models of the quasi-steady and dynamic wake effects on a turbine operating in wake. The analysis concentrates on selected cases for changing conditions of partial and full wake (sweeping wake), respectively, at the offshore wind farm alpha ventus. Atmospheric measurements at the FINO1 meteorological mast and a long-range multi-lidar system are used to initialize and verify flow predictions. Turbine dynamics are extracted from load and SCADA data.

2. Methods

Long-range lidar measurements have been performed to capture the shape and position of the wake wind field (Fig. 1). A particular set of data has been selected during which the turbine AV04 operates in the third row of the wind farm. The configuration enables analysis of a single wake of twelve diameters downstream (12D) from AV10 with non-operating AV07. Moreover, overlapping of two wakes from AV10 and AV07 (12D and 6D, respectively). Simulations are performed for the selected cases in quasi-steady and dynamic conditions.

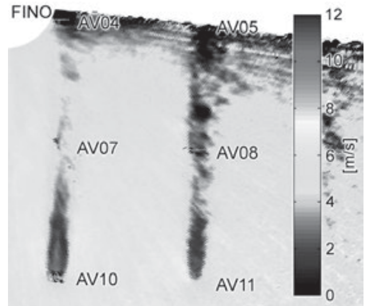

Fig.1: Visualization of line-of-sight wind speed measured with a long-range lidar at FINO1 at alpha ventus. South-north wind generating a sweeping wake from AV10 and AV07 on AV04.

A revised Ainslie approach [1] is applied to simulate the mean wake flow under partial and full wake. Wind turbine power performance is estimated with an effective wind speed approach and compared against SCADA measurements. The wake dynamics effects are estimated applying the Extended Disk-Particle Model (EDPM) [2].

The wake dynamics experienced by the turbine are extracted from load sensors at the wind turbine blades and tower. Finally correlations between wake sweeping dynamics and turbine load variation are presented and conclusions on modeling wake effects are drawn.

3. Acknowledgments

The research is supported by the Federal Ministry of Economy and Energy in the scope of the RAVE project OWEA Loads (FKZ 0325577B).

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FRAUNHOFER IWES WIND LIDAR BUOY VALIDATION

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1. Floating LIDAR System

The Fraunhofer IWES Wind Lidar Buoy (Fig. 1) is a floating Lidar system integrating a Leosphere Windcube® or ZephIR 300 Lidar device in an adapted marine buoy.
Its compact design, an autonomous and robust power supply system and an efficient data processing and communication setup ensure fast and flexible offshore wind measurement campaigns at minimal costs. The motion correction algorithm developed by Fraunhofer IWES guarantees a high data accuracy and measurement uncertainties similar to those for offshore mast measurements.

Fig. 1: Fraunhofer IWES Wind Lidar Buoy (© Thomas Viergutz)

1.2 System Validation and Performance Verification

The design of the system was initially validated in a set of hydrodynamic simulations. With an onshore measurement setup, comprising a tilt table (with two degrees of freedom) next to a tall meteorological mast, the effects of the motions were tested for the selected Lidar device including also the developed motion compensation algorithm. The commissioning of the floating Lidar system was first tested near-shore, before it was installed offshore next to FINO1. The offshore test serves as a final validation of the system and as a verification of the system performance providing a quantification of the uncertainty for the floating Lidar device with respect to the reference measurements of the meteorological mast.

2. Tested Measurement Performance

The accuracy of wind measurements by the Fraunhofer IWES Wind Lidar Buoy was tested in intended environment, 45 km offshore in 450 m distance to FINO1 met. mast (German Bight, North Sea) from August-October 2013 and August-October 2014. The comparison (Fig. 2) between floating Lidar and reference mast measurements is comparable to onshore verification results.

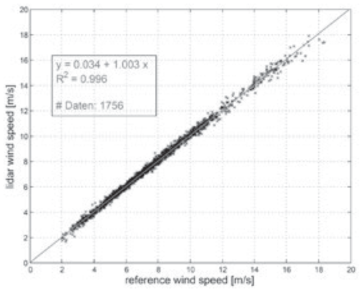

Fig. 2: Results of offshore verification test next to FINO1 met. mast.

OFFSHORE WIND TURBINE POWER PERFORMANCE MEASUREMENT USING A NACELLE MOUNTED LIDAR AND A SECTOR SCANNING LIDAR FROM THE TRANSITION PIECE

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R. Krishna Murthy[3], M. Boquet[3], S. Davoust[4]

1. Introduction

Power performance verification is regularly assessed after completion of wind farm construction. According to the IEC 61400-12-1 standard, the measurement of free wind speed upstream of a wind turbine is required. The conventional solution for carrying out the wind measurement is to erect a hub height met mast at 2.5 rotor diameters from the turbine. This is becoming prohibitively expensive offshore, especially as wind farms are moving further out into deeper waters.
Lidars, on the other hand, can be placed on the turbine itself and measure the wind speed up to 3 or 4 rotor diameters upstream, without the need for dedicated offshore construction. It is therefore an attractive alternative to an offshore mast, at a much lower cost.
Nacelle lidars have been demonstrated to be useful for power curve measurement [1]. Scanning lidars have shown promising results for onshore tests [2]. In this paper we are presenting the results from a measurement campaign carried out offshore with both a nacelle mounted lidar and a scanning lidar placed on a wind turbine transition piece.

2. Measurement set up

The measurement campaign took place on a Siemens 3.6MW turbine in an offshore wind farm, in the North Sea. A hub height met mast with design and instrumentation compliant with IEC 61400-12-1:2005 was erected to the south west of the wind turbine. A two-beam Wind Iris lidar was installed on the nacelle of the wind turbine and measured the horizontal wind speed at 2.5D upstream. Simultaneously, a WINDCUBE 100S was placed on the west side of the turbine, on the transition piece (see Fig. 1). This lidar was set up to scan within a sector of 45 degrees centred on the met mast position and an elevation angle of 14.1°, sensing the wind at a height just above that of the top-mounted cup anemometer. Prior to their deployment offshore, both lidars were calibrated by DTU at their testing facility at Høvsøre, Denmark. The 2-beam nacelle lidar was calibrated according to the procedure previously developed in [3], whereas a new methodology has been developed for calibrating sector scanning lidars.

Fig. 1: Windcube 100S on transition piece of the offshore wind turbine

3. Results

These calibrations provided the essential basis to quantify the lidars' measurement uncertainties; thus allowing a meaningful comparison of the lidar measurements to the met mast offshore, in terms of wind speed and power output. Furthermore we discuss the challenges specific to offshore deployment, e.g. tilt and roll of the wind turbine.

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MEASUREMENT OF TURBINE INFLOW WITH A 3D WINDSCANNER SYSTEM AND A SPINNERLIDAR

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1. Motivation

1.1 Current practice: free wind speed

Wind turbine power performance measurement are based on the relation between the free wind speed, i.e. the wind speed at the turbine location if there were no turbine, and the turbine response in terms of power or loads. Practically, this requires measuring the wind speed upstream of the induction zone of the turbine. However, as the size of wind turbines is increasing, the measurements need to be taken several hundreds of meters away from the turbine. The correlation between the wind measured upstream and the wind at the turbine location is therefore decreasing, especially for turbines installed in complex terrain.

Fig. 1 Left: Picture of the SpinnerLidar on the turbine nacelle; Right: Scan pattern

1.2 New approach: inflow measurement

The UniTTe (Unified Turbine Testing) project (www.UniTTe.dk) aims at developing new procedures for power curve and loads assessment based on wind measurements taken closer to the rotor plane – therefore inside the induction zone – in order to increase this correlation.

2. Measurement set up

This paper is presenting the first measurement campaign of UniTTe. Detailed measurement of the inflow, in front of the 550 kW Nordtank wind turbine (rotor diameter D=40m), at the DTU Risø Campus, have been taken simultaneously with the short-range WindScanner system (www.WindScanner.dk) and the SpinnerLidar [1].

2.1 The short-range WindScanner system

Three time and space synchronized short-range WindScanners were deployed around the turbine to measure the wind velocity vectors in 3 dimensions, along scan trajectories laid out in 3 different planes of 1D by 1.5D, with a spatial resolution of 4 m. The measurements were validated against a sonic anemometer mounted on a mast, at 30 m a.g.l.

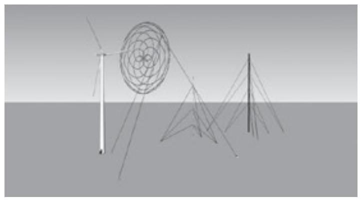

Fig. 2: Measurement set up with the three WindScanner systems around the turbine and the upstream masts

2.2 The SpinnerLidar

The SpinnerLidar, originally designed for spinner-integration, was installed on the top of the turbine nacelle, behind the rotor, and set to scan at 46 m upstream. With its two rotating scan prisms, the SpinnerLidar is able to scan the entire swept rotor area in a few seconds (see scanning pattern to the right in Figure 1) and thus provided measurements with a very high spatial and temporal resolution.

3. Outcome

This is a unique measurement campaign, combining the SpinnerLidar and the short-range WindScanner system. The measurements have been inter-compared with standard anemometry, which will demonstrate the benefits of these new remote sensing wind measurement technologies.

4. References

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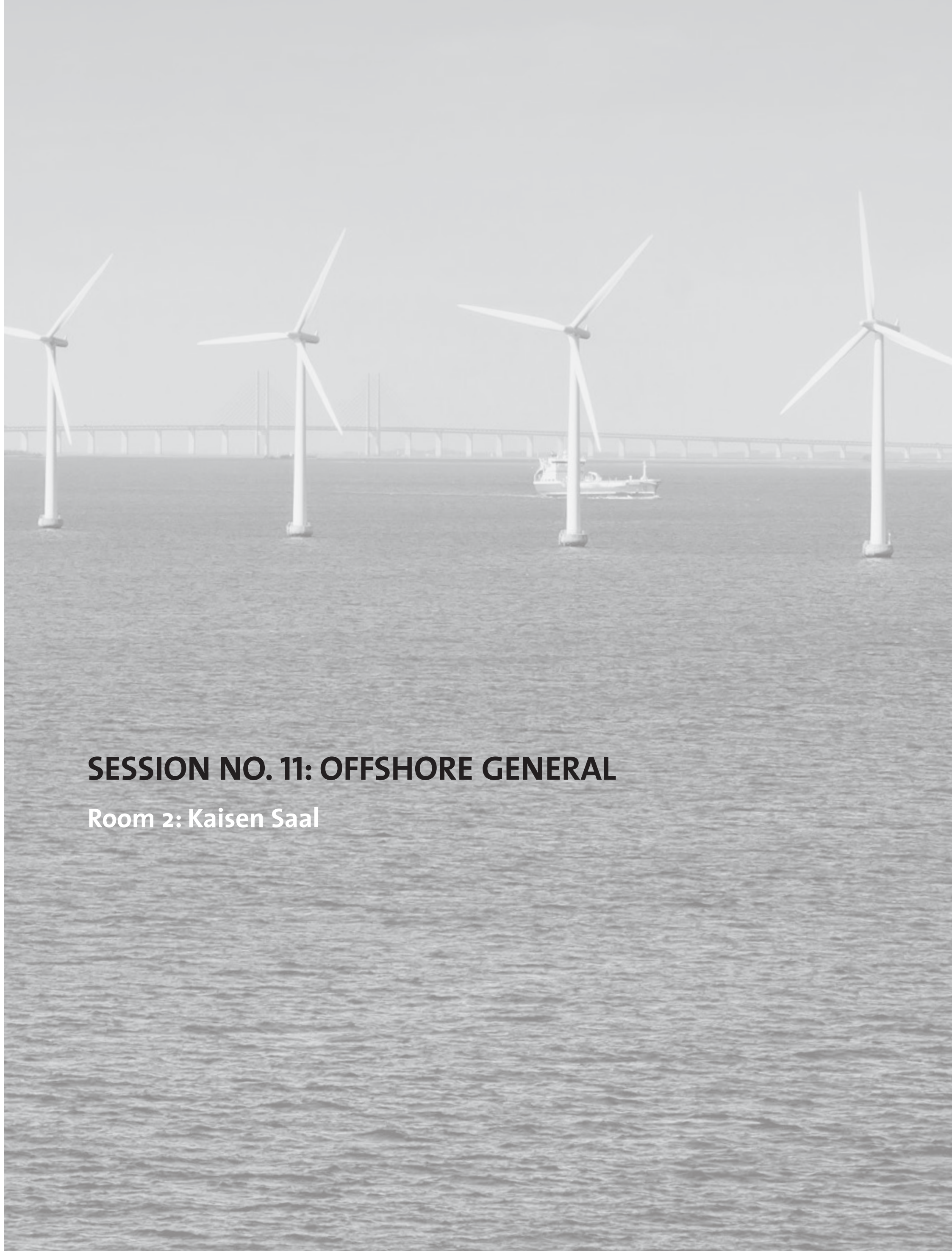

SESSION NO. 11: OFFSHORE GENERAL

Room 2: Kaisen Saal

DESIGN TOOL FOR OFFSHORE WIND FARM CLUSTERS

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Igor Waldl, igor@overspeed.de[2], Presenter, Gerard Schepers, Schepers@ecn.nl[3]

1. Introduction

The Design Tool for Offshore wind farm Clusters (DTOC) is a software tool to facilitate the optimised design of both, individual and clusters of offshore wind farms. DTOC is developed with the support of an EC funded FP7 project with contributions from science partners from the European Energy Research Alliance (EERA) and a number of industrial partners.
The approach is to develop a robust, efficient, easy to use and flexible tool, which integrates software relevant for planning offshore wind farms and wind farm clusters and supports the user with a clear optimisation work flow.
The software includes wind farm wake models, energy yield models, inter-array and long cable and grid component models, grid code compliance and ancillary services models. The common score for evaluation in order to compare different layouts is levelized cost of energy (LCoE). The integrated DTOC software is developed within the project using open interface standards and will be commercially available in spring 2015.

2. Wind farm effect model validation

The EERA DTOC project work has included three benchmark validation tests of several wake models including engineering wake models, CFD models and linearized/parabolized CFD models. The results from Horns Rev 1, Lillgrund and Rødsand-2 show the wake models to compare well to SCADA data. The energy yield and losses have been analyzed. Also the grid connection options and model integration have been done.

3. DTOC optimisation tool

Based on this initial work, the software design has been developed. The industrial partners of the project defined the main tasks to focus on through so-called user-stories, defining the desired functionality of the tool and guiding the development process.

Tool validation

Several application scenarios have been defined and the project partners have calculated a series of potential plans for three situations:
1. developer case of approx. 500 MW wind farm next to other wind farms, 5 MW turbines, not too far from coastline
2. developer case of 1 GW near clusters of wind farms, 10 MW turbines, far offshore
3. far future scenario with large wind farms, several long-distance cables (infrastructure).

One of the innovative new aspects of the tool is closer collaboration between wind energy experts in the fields of aerodynamics, wind conditions, grid planning of offshore wind farms and financial assessment. The tool allows for an integrated work flow on the DTOC platform to optimize offshore wind farm planning.
Our presentation will focus on the implemented DTOC tool functionality, user options, and key results from selected modelling calculations.

4. Conclusion

The EERA DTOC tool presents a new, fully integrated approach to wind farm and wind farm cluster optimisation: Potential assessment including the influence of large scale wind farm clusters, wake effect calculations of large offshore wind farms, electrical infrastructure planning and grid compliance. LCoE is the score for inter-comparison of different layout variants, including cost of foundations, O & M, and other expenditures. The DTOC tool will be presented life during the DEWEK exhibition. www.eera-dtoc.eu/

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WEATHER RISK OPTIMIZATION COVERING THE OFFSHORE WIND FARM PROJECT LIFE CYCLE

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1. Project Life Cycle

1.1 Background

The life cycle of an offshore wind farm can be divided into the stages project development, planning & design (P&D), transport & installation (T&I), operation & maintenance (O&M) and decommissioning. In each stage, the resulting weather risk must be assessed and handled according to specific requirements, boundary conditions as well as the overall project progress in order to reduce the costs.

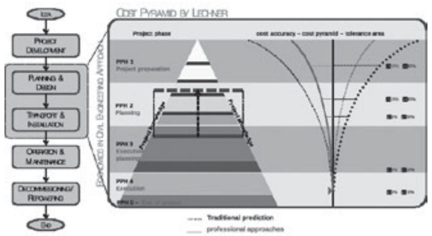

Fig. 1: Project Life Cycle

1.2 WaTSS Approach and Customization

The innovative WaTSS – Weather Time Series Scheduling – approach is based on the simulation of activities using sea state and/or weather time series considering restrictive parameters like wave height or wind speed. Furthermore additional boundary conditions (e.g. guideline DNV-OS-H101 “Marine Operation”) can be considered. As input weather time series, model data and measured data can be used, respectively.
For each life cycle stage, the WaTSS method is individually implemented and applied depending on the special requirements. This includes different issues, strategic approaches, methods of analysis etc. Different implementations are explained and the results are shown by analyzing project stages of the Fraunhofer IWES virtual reference wind farm. Finally further fields of application and advanced WaTSS analysis methods are summarized.

2. Implemented WaTSS Approach, case study

An example for a T&I analysis during the realization stage is presented. Here the real project progress during the installation is evaluated and compared to the existing plans. Also the possible future progress will be analyzed with respect to weather risks. The WaTSS concept, as implemented in the COAST tool, is a simple but powerful approach to evaluate, analyze, optimize and monitor the weather impact on offshore activities. With the analysis of weather dependent activities based on sea state and/or weather time series data, the COAST tool supports better informed, risk based decisions to decrease the cost of energy.

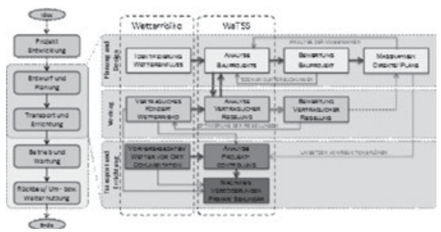

Fig. 2: LC Adopted COAST Approach

3. References

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LOAD REDUCTION FOR FLOATING OFFSHORE WIND TURBINES USING TUNED LIQUID COLUMN DAMPERS

Yulin Si, Hamid Reza Karimi*

1. Introduction

Strong potentials for offshore wind energy have been found in the deep sea areas. According to the extensive experience of marine industry, floating foundations for wind turbines, as shown in Fig. 1, are considered to be an economical and applicable choice, such as submersible, barge, spar-buoy, tension leg, etc.
Different with fixed-bottom wind turbines, one big challenge for floating wind turbines is the platform motion, which will heavily increase the load on the nacelle and tower due to the high inertial and gravitational forces. This might cause severe fatigue and ultimate damage on the blades, tower base, nacelle-tower bearing. Therefore, development of an effective load reduction strategy is necessary for the design of floating wind turbines.

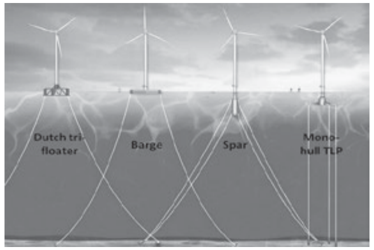

Fig. 1: Different Floating wind turbine concepts

2. Load Reduction Strategy

This work proposes to use semi-active structural control method with tuned column liquid dampers (TLCD) installed in either nacelle or floating foundation, as illustrated in Fig. 2, for floating wind turbine load reduction.

Firstly, simplified mathematical models are established for different floating wind turbine concepts and further verified [1]. Secondly,different size and installation choices of TLCD are investigated, and a semi-active control strategy is also designed to tune the cotrollable valve in TLCD. Thirdly, fully coupled nonlinear simulations are performed in FAST-SC [2] to evaluate its effectiveness.

Simulation results show TLCD with appropriate size and installation can potentially reduce the wind turbine loads, and it is possible to acheive more load reduction by properly controlling the valve in TLCD.

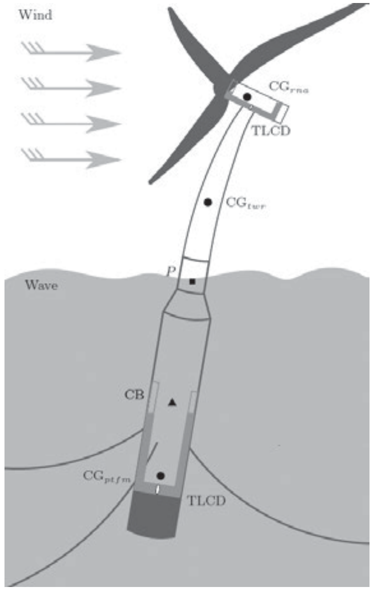

Fig. 2: TLCD installed in a spar-type floating wind turbine

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SESSION NO. 11: OFFSHORE GENERAL DEWEK 2015

SIMULATION-BASED EVALUATION OF OPERATION AND MAINTENANCE LOGISTICS CONCEPTS FOR OFFSHORE WIND POWER PLANTS

Torsten Münsterberg, Carlos Jahn*

1. Introduction & Problem

The German Federal Government recently reduced its targets for offshore wind capacity to 6,500 MW in 2020 and 15,000 MW in 2030 [1]. Nevertheless the electricity production costs of offshore wind energy are too high. They currently range from 119/MWh to 194/MWh. To make offshore wind energy economically viable, the production costs should be reduced for projects after 2020 below 100/MWh [2]. The operating costs (OPEX) have a share of about 25-30 percent of the electricity production costs [3] and provide significant cost saving potential [4]. Because of little experience in the operation of offshore wind power plants, there are no standardized logistics concepts within the industry [5].
For the long-term economic success integrated logistics concepts have to be developed for offshore wind power plants.

2. Research Approach

In this article the performance of logistics concepts for preventive and corrective maintenance actions for offshore wind power plants are investigated and evaluated. To investigate these complex situations with stochastic distributed events an extensive simulation model was developed by Fraunhofer CML. This model was tested with various application scenarios.
Forms of onshore and offshore-based logistics concepts can be fully assessed by diverse variations of input parameters, e.g. number of vessels, number of personnel, failure rates of turbines and weather conditions. The simulation model consists of predefined building blocks, which represent the typical elements of the landside supply chain, port logistics and the sea-side environment. These include offshore wind turbines, vessels, helicopters, personnel and work orders. The simulation model in Enterprise Dynamics is controlled via Excel to make it user-friendly. After a simulation run the results are exported back to Excel.

3. Results

For a wind power plant with 100 wind turbines (each 5 MW) and a distance from the service port of 50 km, the results show for onshore-based concepts that two crew transfer vessel (CTV) with helicopter support are the most economical approach with an availability of 94.6 percent. Without helicopter support three CTV lead to the best availability of 90.3 percent.
The investigation underscores the great benefits of using a helicopter. It emphasizes that the concepts should be flexible throughout the year. Especially in the summer months, when the annual maintenance is due, the use of additional vessels and personnel is essential.

4. References

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A NEW EFFICIENT TECHNOLOGY TO REDUCE OFFSHORE PILING NOISE

Karl-Heinz Elmer[1], Benedikt Bruns[2], Christian Kuhn[2]

The piling noise during the construction of offshore wind farms is potentially harmful to marine life, in particular to marine mammals. The increasing number of prospected offshore wind turbines in the future needs effective and reliable noise reducing methods. The German authority BSH has set a standard level of 160 dB (SEL) at a distance of 750 m from pile driving, other countries are following with restrictions.

The new underwater noise mitigation technology of Hydro-Sound-Dampers (HSD) has been developed in the last years and uses open curtains of robust air filled elastic balloons with high underwater noise reduction effects and special PE-foam elements with high dissipative effects from material damping, to reduce piling noise. All elements can be fully controlled and HSD-systems are independent of compressed air, not influenced by tide currents and easy adaptable to different applications. With about 20t – 30t the whole HSD-systems are very light and cost-efficient.

The background of the innovative underwater noise mitigation technology and main results of the just finished BMU-research project "Hydro Sound Dampers" of the Institute of Soil Mechanics and Foundations (IGB) of the Technische Universität Braunschweig are explained.
The results of laboratory tests and offshore tests of the noise mitigation confirm the results of new numerical simulations of underwater noise propagation and mitigation.
The first serial offshore applications in 2014 of the new HSD-system of OffNoise-Solutions have shown reliable performance and very good noise mitigation results. Measurements show the high potential of the HSD-noise mitigation technology, even in the important lower frequency range around 100 Hz of todays large hydraulic hammers. These results with HSD-systems of different offshore applications in 2014 will be presented for the first time, practical experiences and combinations with other noise mitigation methods will be discussed. To reduce the mobilization time down to several minutes, a new HSD-system will be applied to the monopoles of an OWF in the North Sea in 2015, with the complete HSD-system is hanging below a gripper.

These serial applications of Hydro-Sound-Dampers technology demonstrate a new effective way to reduce offshore piling noise.

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DEWEK 2015

SESSION NO. 12: SIMULATION BLADE

Room 3: Lloyd

NUMERICAL INVESTIGATION OF UNSTEADY AERODYNAMIC EFFECTS ON THICK FLATBACK AIRFOILS

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1. Introduction

Flatback airfoils are introduced to increase aerodynamic performances at the inner region of wind turbine blades. The flatback reduces the adverse pressure gradient, which in turn increases sectional maximum lift coefficient and lift curve slope, and reduces sensitivity of the lift characteristics to surface soiling [1]. Fig. 1 shows the lift polar of Sandia flatback airfoils [1] for FB-3500-0050, -0875, and -1750 which have 35% maximum thickness and trailing edge thicknesses of 0.5%, 8.75%, and 17.5%, respectively. When the blade root operates at high angle of attack (AoA) and stalls, centrifugal force transports this separated boundary layer from the root towards the middle region of the blade and it has adverse effects on the performance of the blade [2]. However, there are only limited studies available on this matter. Therefore, this paper is intended to gain more information on the unsteady characteristics of flatback airfoils using CFD.

2. Unsteady Calculations

Unsteady numerical calculations have been performed using the CFD code FLOWer. The (URANS) SST k-ω turbulence model is employed. Dual time-stepping is utilized to obtain second-order accuracy in time. Tripped conditions are modelled by fixed transition at 2% and 5% on the suction and pressure side, respectively. The predicted lift coefficient shows a good agreement to available measurements [1], see figure 1. The predicted Strouhal number based on the trailing edge thickness is shown in Fig. 2 and compared to DU97-Flatback airfoil measurement [3]. The value increases with the trailing edge thickness and it is independent of the lift coefficient before stall. Then it starts to decrease as the local AoA increases. The unsteady characteristics and flow phenomena of flatback airfoils and the dependency on the thickness are discussed in more detail in the present paper.

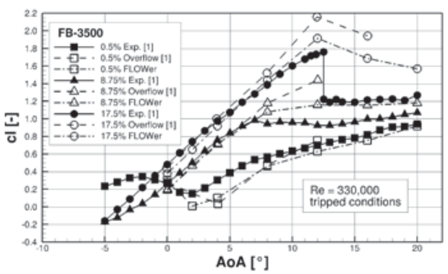

Fig. 1: Lift coefficient of flatback airfoils

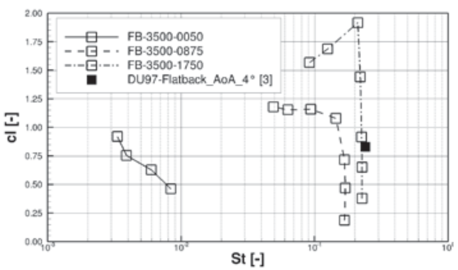

Fig. 2: Strouhal number of the lift coefficient
(The arrow indicates the increase of the local AoA).

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ANALYSIS OF A STRUCTURAL-AERODYNAMIC COUPLED METHOD FOR NONLINEAR AEROELASTIC RESPONSE OF LARGE-SCALED HAWT

LIAO Mingfu[1], LYU Pin[2]

Abstract

Aeroelastic effect is becoming an important issue due to the larger, lighter and more flexible blades of large-scaled HAWT. In this study, a structural-aerodynamic coupled method has been developed to predict the nonlinear aeroelastic responses by coupling a nonlinear beam model based on geometrically exact beam (GEB) theory for blades structural dynamics with a free-vortex wake (FVW) model for the prediction of unsteady aerodynamic loads. The two models are coupled by exchanging the data based on a partitioned loosely coupled methodology. At first, the nonlinear beam model is validated by validation cases which all show a good agreement with results obtained by other authors. Subsequently, by comparing the data of MEXICO experiment with the FVM model, the capability of the model to accurately predict the aerodynamic loads of rigid blades is also validated. Finally, the numerical responses for NREL 5 MW RWT are estimated through fluid-structure interaction simulations. The blade behaviour is also compared with numerical results obtained from different aerodynamic models. The results show that the coupled method is capable of evaluating blade nonlinear responses for large-scaled HAWT.

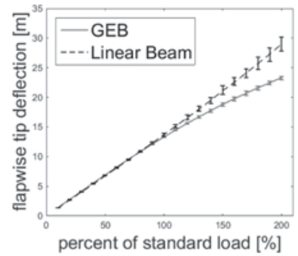

Fig. 1 peak value of flapwise tip deflection under scaled constant loads

Application on NREL 5MW

Fig. 1 shows the peak values of tip flapwise deflection under different scaled loads. The standard loads are calculated based on undeformed NREL 5MW blade without tile, yaw, precone and yaw angle at rated wind speed. It shows the linear beam starts to fail when the scaled factor is larger than 0.8.

Fig 2 shows the response of NREL 5MW blade at rated wind speed. The response from the nonlinear aeroelastic model is larger than from FAST. But as shown by Fig 3, when flap stiffness and edge stiffness are both adjusted to 50%, the average deflection from the nonlinear aeroelastic model is almost the same as from FAST, while the amplitude is slightly larger.

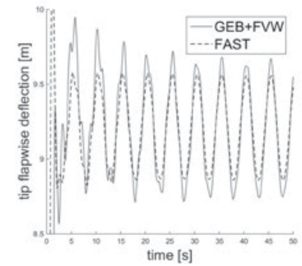

Fig. 2 tip flapwise deflection of NREL 5MW blade

Conclusions

(1) The GEB solver has the capability to simulate the response for large deflection, while the linear beam theory totally fails.
(2) The results of FVM show better agreement than BEM against to the MEXICO experiment data.
(3) To study the aerodynamic characteristic of large deflection, the aeroelastic model with GEB and FVM solver is a reliable nonlinear aeroelastic analysis tool for large wind turbine blades.

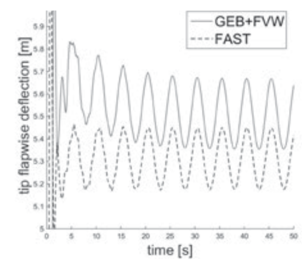

Fig. 3 tip flapwise deflection of NREL 5MW blade with 50% scaled stiffness

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DAMPING MODEL FOR FATIGUE TEST PLANNING OF A WIND TURBINE BLADE

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1. Introduction

Recent treads in wind turbine technology have been towards larger blades that can harness more wind energy. Fatigue testing of these larger blades poses a particular technical challenge as they must be oscillated with an amplitude of several meters for longer than one million cycles. An innovative method to overcome this challenge is to exploit the resonance phenomenon of a wind turbine blade. To perform resonance-type fatigue testing, the required energy to oscillate a test blade should be estimated based on the harmonic analysis of the blade using its modal damping ratio. A model that can predict a large wind turbine blade's modal damping ratio during resonance-type fatigue testing with accuracy up until now has not been developed but is needed. In this study, we developed a damping model for resonance-type fatigue testing. Three kinds of damping phenomena during the testing were modeled and then merged into a single modal damping ratio based on energy balance. Three characteristic constants in the model were determined from measured test data of a 48.3 m 3MW class IIA blade and a 44.0m 3MW class IA blade in various test conditions, so a complete damping model was constructed.

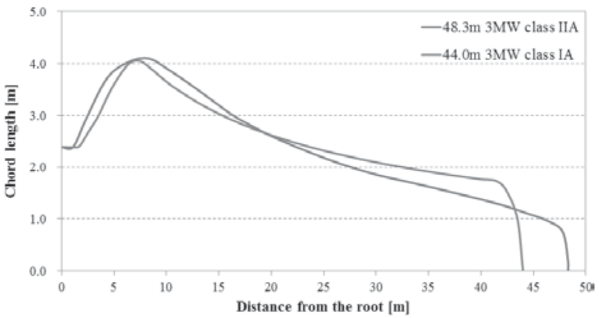

Fig. 1: Chord distribution of the two test blade.

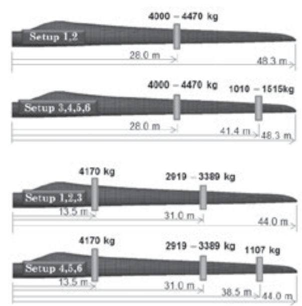

Fig. 2: Test setups for measuring damping ratios: (a) 48.3m 3MW class IIA blade and (b) 44.0m 3MW class IA blade.

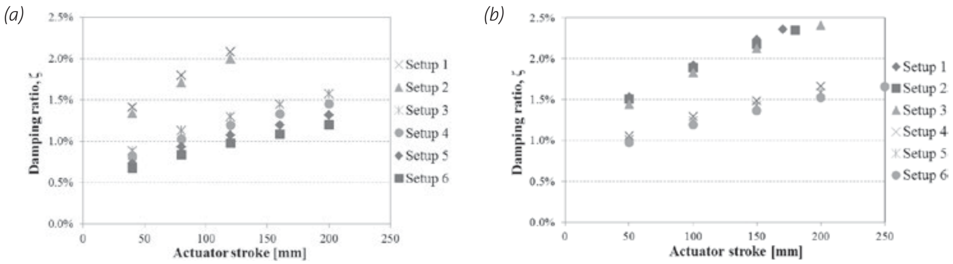

Fig. 3: Measured damping ratios: (a) 48.3m 3MW class IIA blade and (b) 44.0m 3MW class IA blade.

DEWEK 2015 SESSION NO. 12: SIMULATION BLADE

RANS BASED PREDICTION OF THE AIRFOIL TURBULENT BOUNDARY LAYER – TRAILING EDGE INTERACTION NOISE FOR MILDLY SEPARATED FLOW CONDITIONS

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1. Abstract

The turbulent boundary layer – trailing edge interaction noise (TBL-TEN) is considered as the most dominant noise source of a wind energy rotor. The fluctuating pressure near the wall, induced by the interaction of the turbulent eddies within the boundary layer, is scattered due to the trailing edge and propagates into the far-field. A model which was originally proposed by Parchen [1] and enhanced by Kamruzzaman [2] is used in the present study to compute the spectrum of the TBL-TEN. For mildly separated flow conditions it is enhanced with the approach of Schuele [3]. The extended prediction model has been verified by comparison to new aeroacoustic measurements. The measurements were performed in the institute's laminar wind tunnel.

2. Computational Methods

For the analyses of the aeroacoustics a CFD solution is necessary. Therefore the DLR code FLOWer is used, which solves the unsteady RANS equations and offers different turbulence models. In a first step the aeroacoustics model uses the CFD solution to predict the spectrum of the wall pressure fluctuations at the trailing edge. In a second step the far-field noise spectrum is calculated. For mildly separated flow conditions the recirculation zone with its back flow is supposed to have a negligible impact on wall pressure fluctuations and is not included in the computation.

3. Results and Comparison to Measurements

A large test matrix, with variations of the angle of attack as well as the Mach number and the Reynolds number, is used to examine the aeroacoustics model. The turbulence model of the CFD solver is also varied. All numerical results are compared to measurements. For a comprehensive verification not only the wall pressure but also far-field spectra are scrutinized, also the boundary layer properties are examined. Figure 1 illustrates the result for the far-field spectrum exemplarily. In this particular case the flow separates at 99% of the chord length at the suction side. The distinct congruence is obvious.
The paper will show details about the analyzed test matrix and the comparison to the measurements.

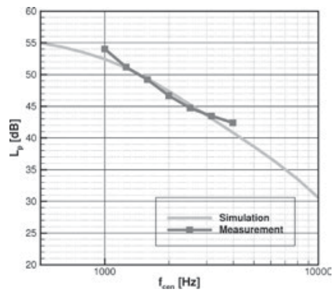

Fig. 1: Comparison between measurement and simulation

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PARAMETERIZED ANALYSIS OF SWEPT BLADES REGARDING BEND-TWIST COUPLING

Alper Sevinc[1,2], Oliver Bleich[2], Claudio Balzani[1], Andreas Reuter[1,2]

1. Introduction

Increasing rotor diameter and hence increasing blade length cause higher loads not only at the blade itself but at the complete turbine system. Larger swept areas include higher aerodynamic loads caused by effects like turbulences, eddies, shear, etc. and imply a complex load state on local positions at the blade. Therefore load reduction systems decreasing the aerodynamic heterogenic loading become more important. One of these methods which can be achieved by sweeping blades is investigated in this paper.

1.1 Swept blade geometry

Load reducing effects of swept blades were investigated successfully in several research programmes [1], [2]. A first parametric study has been already performed with different parameter settings regarding tip offset and sweep curve exponent [2]. For the parametric study presented here, additional variables like the sweep start position along the blade length and other curvature functions are considered to analyse the different influence of the curvature shapes regarding load reduction and twisting (see Fig. 1).

Fig. 1: Examples for different curvature shapes of swept blades

2. Determination of the weighting factors

For the determination of the loads and time series the turbine model is implemented in an aero elastic simulation software. Design driven load cases for fatigue and extreme loads are considered for the calculation of the influence of the parameter weighting. Extreme loads and damage equivalent loads are determined based on the output of the aeroelastic simulations. Afterwards the influence of the change of every single parameter will be used for the determination of functions regarding torsional, edgewise and flapwise loads. Finally a multi-variable cost function including the different weightings of the single parameters can be generated.

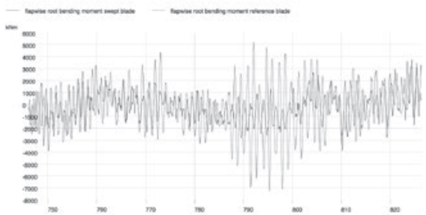

Fig. 2: Aeroelastic simulation of the flapwise bending moment

3. References

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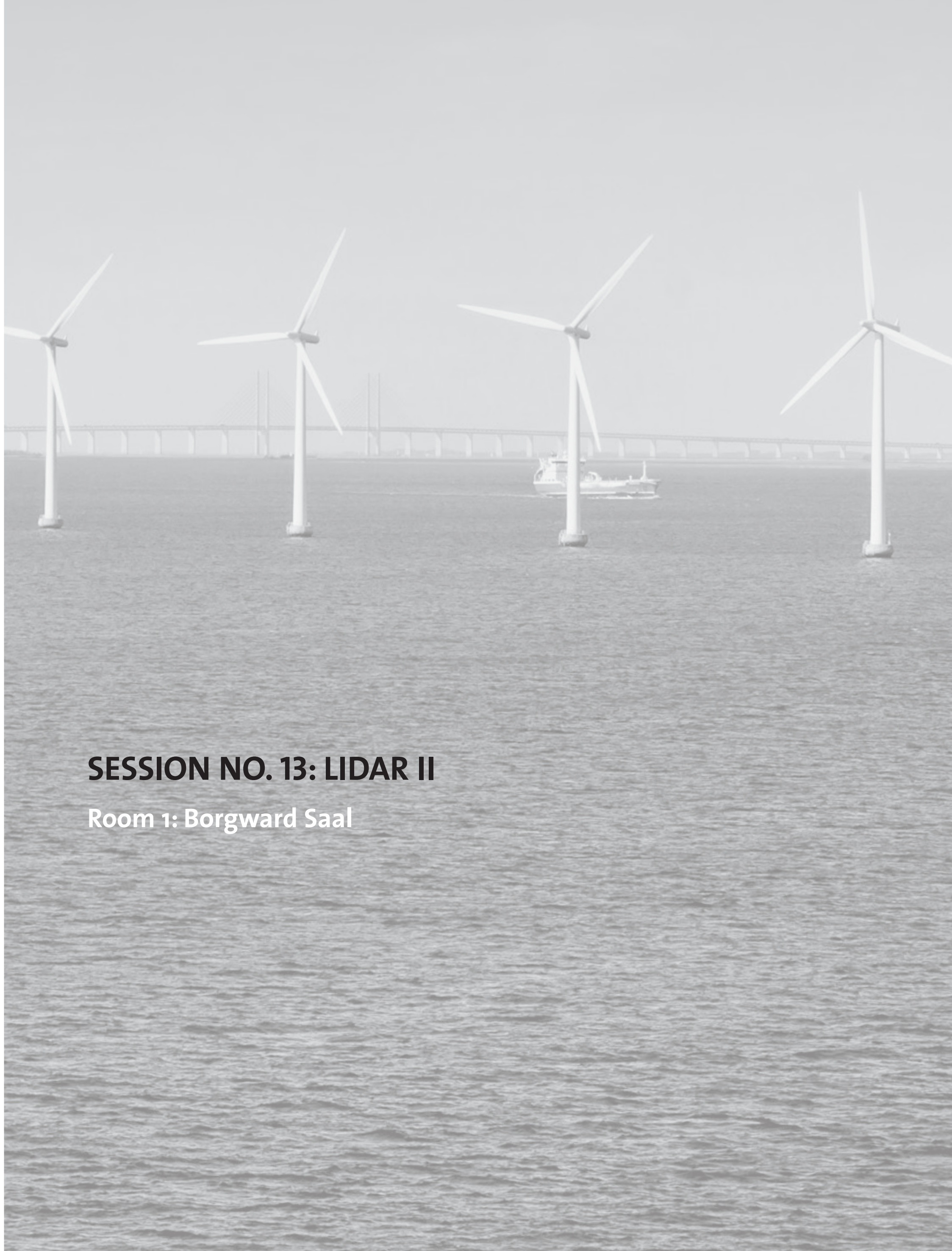

SESSION NO. 13: LIDAR II

Room 1: Borgward Saal

CALIBRATION PROCEDURES FOR NACELLE-MOUNTED PROFILING LIDARS

A. Borraccino[1], M. Courtney[1], M. Harris[2], C. Slinger[2], S. Davoust[3], R. Wagner[1]

1. Introduction

1.1 Use of profiling lidars for power performance assessment

It is now commonly accepted that ground-based profiling LIDARs can improve power performance assessment by measuring simultaneously at different heights [1]. On the other hand, even though they are unable to measure the wind shear, two-beam nacelle lidars studies show promising capabilities to assess power performance [2] and avoid the erection of expensive meteorology masts, especially offshore. A new generation of commercially developed profiling nacelle lidars combine the benefits of both.

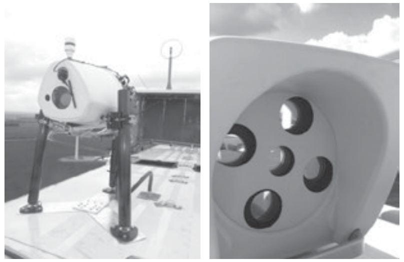

Fig. 1 Left: "Demonstrator" (credits: ECN/XEMC Darwind/Avent Lidar Technology)
Right: ZephIR Dual Mode (credits: ZephIR lidar)

1.2 The need for calibration procedures

The fundamental reason for developing calibration procedures is to assign uncertainties to the measured parameters. Calibration procedures for two-beam pulsed lidars have been published in [3]. We have developed new procedures for profiling nacelle lidars (both pulsed and continuous wave).
In this paper, we will present the procedures used for the calibration of newly developed nacelle-based profiling lidars and the results obtained.

2. Calibration procedures principles

The outputs of a profiling lidar are usually reconstructed parameters (e.g. horizontal wind speed), mathematically derived from a number of measurements of radial wind speed (RWS) at different heights. The new procedures are based on individual RWS calibration. Uncertainties are then derived by combining the RWS uncertainties through the reconstruction algorithms. This method is referred as "white box" in contrast with a "black box" calibration (direct comparison of the reconstructed outputs to a reference instrument).
The question of uncertainties for complex wind characteristics derived from profiling nacelle-based lidars (shear, veer, turbulence intensity) can be addressed much more comprehensively using the white rather than the black box method.

3. Results

Two profiling nacelle lidars, an Avent Lidar Demonstrator and a ZephiR DM have been calibrated at DTU's test site for large wind turbines, Høvsøre. They have been placed on the ground, their geometry measured (e.g. cone or opening angles), and their internal inclinometers calibrated. The line of sight (LOS) direction is derived using a sonic anemometer retrieving the wind direction. The RWS along the LOS have been compared to the measurements from a cup anemometer top-mounted on a mast. Finally, uncertainties of the LOS speed calibration have been determined as well as those of the reconstructed parameters.

4. References

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DETERMINATION OF STATIONARY AND DYNAMICAL POWER CURVES IN INHOMOGENEOUS WIND FLOW USING A NACELLE-BASED LIDAR SYSTEM

I. Würth[1], A. Rettenmeier[1], P. W. Cheng[1], M. Wächter[2], P.Lind[2], J. Peinke[2]

Introduction

The newest edition of the IEC standard 61400-12 concerning power performance verification measurements of wind turbines will allow the use of lidar devices as wind speed measurement instruments. Due to increasing rotor diameters and thus an increasing influence of the inhomo-geneous inflow on the power output, devices that are able to measure the wind speed over the rotor swept area become necessary, especially when the high costs of met masts are considered. This paper focuses on the use of nacelle-based lidar measurements gathered at the offshore test site alpha ventus for the determination of stationary and dynamical power curves investigating the effect of inhomogeneous flow.

Applied approaches

Within the joint research project LIDAR II carried out by SWE and ForWind, the nacelle-based lidar scanner developed at SWE [1] is mounted on the nacelle of the wind turbine AV4 facing upwind to measure the inflowing wind field simultaneously in five planes in front of the rotor. The system allows for various scan patterns to be implemented, thus capturing the wind speed at measurement points over the whole rotor area. Following previous investigations [2], to gain a rotor equivalent wind speed representative for the flow conditions over the rotor area, a moving average is applied to each measurement plane. The respective planes are then combined considering Taylor's frozen hypothesis. Besides the lidar measurements, the turbine performance data are recorded which enable investigations on the power performance. Two approaches to determine the power curve are applied. Firstly the conventional stationary approach as described in the IEC using 10 minute averages of wind speed and power data is carried out. Secondly a method developed at ForWind to analyze the dynamics of the power conversion process and derive a power curve from high frequency measurement data is applied. The data which is used as input for the two methods is filtered according to several criteria to investigate the influence of the inhomogeneous flow. Deviating from the IEC standard, data from sectors where the inflow of the AV4 is affected by the wake of the adjacent turbines are taken into account for the analysis. Additionally, the effect of different turbulence intensities on the power output is studied; also refer to [3]. The expected outcome is a better understanding of the turbine's behavior in non IEC conform inflow conditions. Especially when investigating wake effects, the usage of lidar measurements is expected to be beneficial as they are able to capture wake losses and spatial variations of the wind field.

References

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[1] Stuttgart Wind Energy (SWE), University of Stuttgart, wuerth@ifb.uni-stuttgart.de
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COMPARISON OF THE ROTOR EQUIVALENT WIND SPEED OF GROUND- AND NACELLE-BASED LIDAR

Martin Hofsäß, David Kozlowski, Tom Siebers*, Prof. Dr. Po Wen Cheng

1. Introduction

The vertical wind profile has a big influence on the power output of wind turbines (WT). Point measurements of the wind speed at hub height represent the wind conditions only partially compared to swept rotor area of the WT. This results in a wide scatter of the measured power curve. With ground- and nacelle-based lidar systems, it is possible to measure the wind conditions between the bottom and top tip heights of most WT. This opens up new possibilities in determining the power curve [1]. In order to reduce the influence of the vertical wind profile on the electrical power output, the model of the rotor equivalent wind speed (veq) [2] can be used. In this work – carried out in the research project "Lidar complex" founded by the BMWi – the veq from the ground-based lidar and from the nacelle lidar will be compared with the wind speed measured with a cup anemometer which is installed at hub height on a meteorological mast. The effect on power curve will be analysed in terms of the differences in the annual energy production (AEP).

2. Measurement campaign

The measurement campaign (Sep 2013 – Apr. 2014) took place in an IEC-compliant site near Wismar, Germany. The schematic structure is shown in (Fig. 1). The met mast is equipped with 1st Class cup anemometers, the ground-based lidar is a Windcube V2 of Leosphere and the nacelle-based lidar is the SWE lidar scanner [3]. The ground-based lidar was placed next to the met mast first to allow a direct comparison with the hub height cup anemometer and second to measure farther up to the tip height of the WT. It has measured at eleven heights. The nacelle-based system was installed on the nacelle of a WT with 95 m hub height and a rotor diameter of 109m. A 5x5 grid with equivalent intervals as scan pattern was used, which covers the complete rotor diameter.

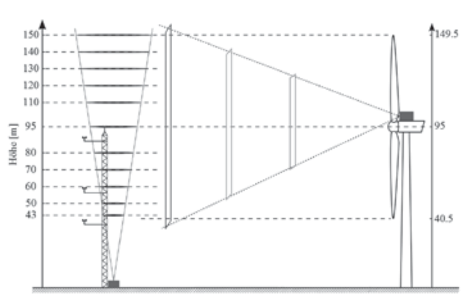

Fig. 1: Measurement set up (solid squares are the lidar systems)

3. Approach

The special feature of this measurement campaign is the direct comparison of a ground-based and a scanning nacelle lidar system with a met mast. For both lidar systems, the approach to calculate the veq was used as described in [1][2]: the average of the wind speed weighted with the size of the corresponding rotor plane segments For the calculation of AEP, Weibull distributions are determined for veq and hub height wind speed [1].

4. References

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SESSION NO. 13: LIDAR II DEWEK 2015

POWER CURVE FILTERED WITH TI MEASURED WITH A TWO-BEAM NACELLE LIDAR

Rebeca Rivera Lamata, Beatriz Canadillas*, Ulrike Bunse*

1. Introduction

1.1 Need of proxy filters to atmospheric stability in power curve verification tests

In most power curve specifications delivered by wind turbine manufacturers the conditions for Turbulence Intensity (TI) and shear profiles are usually restricted to avoid non-neutral atmospheric conditions during the guarantee power curve verification test.

Those shear and TI conditions are normally monitored with the meteorological mast used as reference measurement according to power curve IEC standard [1], but additionally instrumented with at least two levels of wind speed to derive a shear profile. However, the use of a metrological mast offshore for power curve tests is very limited due to extreme cost. Instead new remote sensing technologies offer cost advantages with promising results.

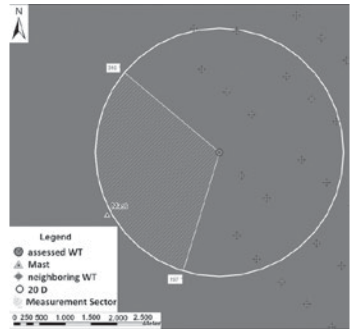

Fig. 1: Measurement set up

In the example provided, the effects of filters on the power curve results are investigated using two methods: shear and TI measured with medium distance meteorological mast and TI measured with a two-beam nacelle LiDAR.

1.2 Measurement set up

In Figure 1 the overview of the measurement set up with the assessed turbine, measurement sector and indicative distance to the metrological mast is depicted. The turbine under test is equipped with a two-beam nacelle LiDAR, which is used as wind speed input for the power curve following the procedure described in [2].

2. Experimental results

Power curves resulting from all valid data and filtered data bases are assessed on the Cp curves, which are shown in Figure 2:

The results show the TI measured two-beam nacelle LiDAR has worked as sufficient proxy to atmospheric stability for the power curve measured, which opens potentials for guarantee verification tests executable offshore at standard onshore costs.

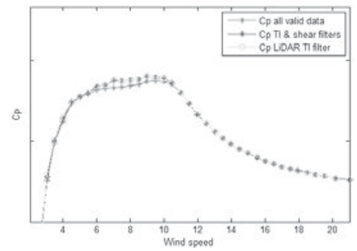

Fig. 2: Effects of different filters on the Cp curve

3. References

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ROBUST LOW COST OFFSHORE POWER CURVE TESTS WITH LIDAR

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1. Introduction

Testing the power performance of offshore wind turbines is an important part of operating an offshore wind farm. The key impediment to offshore power curve tests so far has been the high cost. Hitherto, it has been necessary to install an expensive offshore met mast to obtain the necessary measurements. The ability to install scanning lidar on the transition piece of an offshore wind turbine provides a valuable opportunity to eliminate the cost of the offshore met tower and make highly cost-effective measurements.

A scanning lidar can be installed on the access walkway of the transition piece. The lidar will be set up to implement scan geometries that allow wind data to be acquired at hub height 2.5 rotor diameters upwind of the test turbine. This setup complies in most respects with the latest draft version of the revision of the IEC I61400-12-1 standard. This set up has been used at turbine AV07 at Alpha Ventus Offshore Wind Farm. The accuracy of the data has been verified against the FINO 1 measurement platform.

2. Implementation

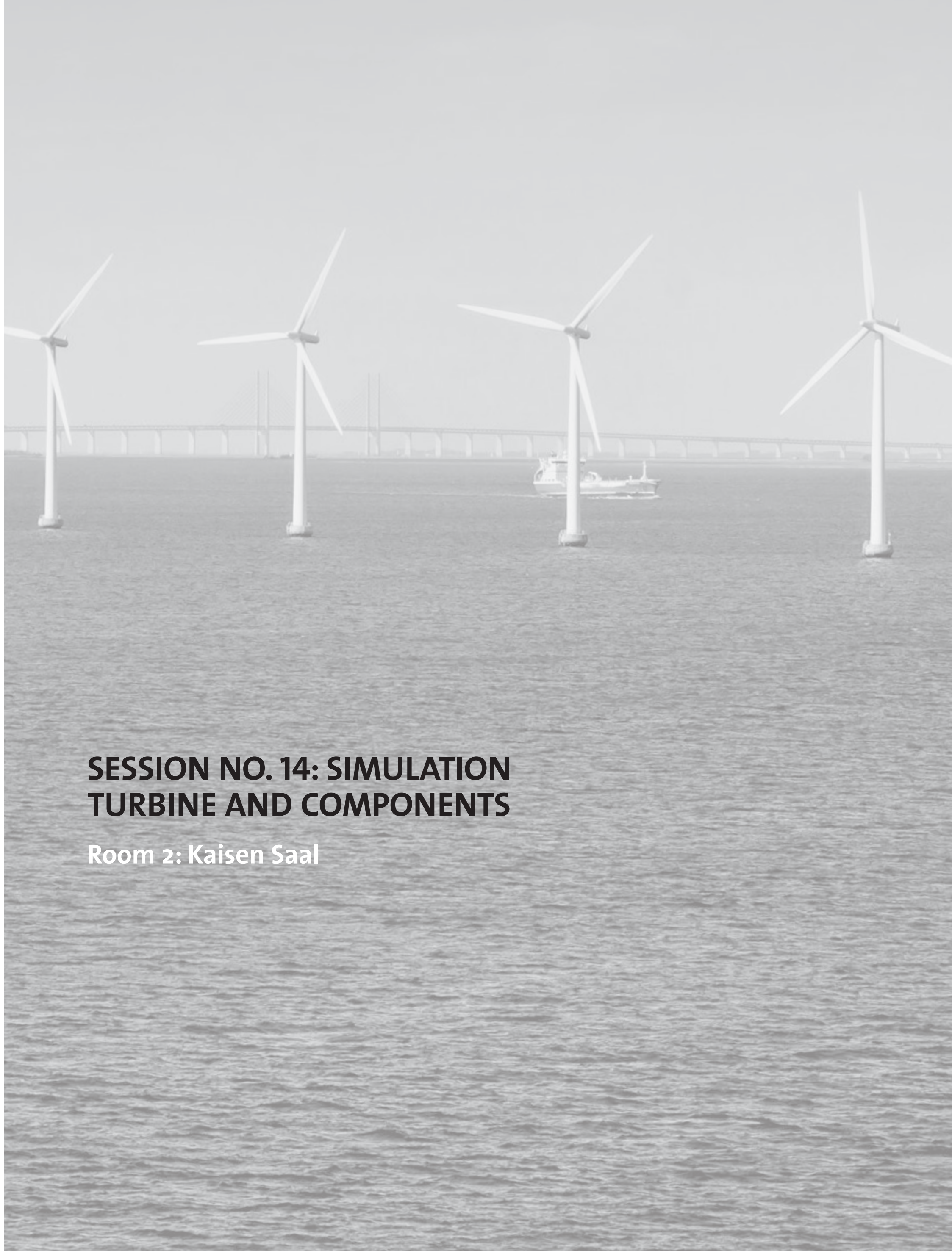
A scanning lidar was installed on the transition piece of AV07 in Alpha Ventus Offshore Wind Farm on 18th February 2013. One of the tasks scheduled for the lidar was the measurement of the wind turbine power curve. The set up needed to be compliant with the draft 2nd edition of the power curve test standard IEC 61400-12-1. This requires "ground based" lidar methods. Nacelle mounting is not compliant, but. Mounting on the transition piece satisfies this requirement. A further IEC requirement is measurement at hub height 2.5 rotor diameters upwind of the test turbine. The measurement accuracy was verified against the FINO1 reference mast approximately 900m from AV07. The results showed excellent agreement, consistent with onshore tests, with both correlation coefficient R2 and regression slope m exceeding 0.98% acceptance criteria. The procedure has been independently reviewed. The transition piece mounting of a lidar device at one turbine also allows power curve tests of multiple offshore wind turbines in the vicinity during a single test campaign, further reducing the costs associated with power curve tests.

3. Conclusion

The methodology described for installing lidar on the transition piece of an offshore wind turbine complies with the draft 2nd edition of the power curve test standard IEC 61400-12-1 to the fullest extent possible without a met mast. The results of measurements performed at Alpha Ventus confirm the suitability of this method. The measurements showed excellent agreement with reference anemometry, with both correlation coefficient R2 and regression slope m exceeding 0.98% acceptance criteria. The cost of the power curve test undertaken using this lidar method is less than 1% of the cost of the equivalent met mast based test.

The presentation will promote an understanding of robust lidar methods for offshore power curve tests which are cost effective and compliant with IEC standards.

A well-documented, independently reviewed and repeatable procedure for implementing this method will be presented.



SESSION NO. 14: SIMULATION TURBINE AND COMPONENTS

Room 2: Kaisen Saal

IMPROVED DESIGN OF WIND TURBINES BY COMBINING OF MEASUREMENT AND SIMULATION

Prof. Dr.-Ing. Berthold Schlecht, Dr.-Ing. Thomas Rosenlöcher
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The dimensioning of drive train components can be done with accurate knowledge of the acting loads in most cases by use of the present regulations and standards. In addition, the possibilities of the finite element method are used to determine stress conditions and to find optimised solutions for design tasks. Regardless of the selected calculation approach, detailed statements to safety factors are only possible, if accurate in-formation on the occurring loads over the planned operation time are available.
The specification of design loads for standard tasks of the drive technology, like the supply of drive energy to realise continuous or periodically variable processes, can be done simply under consideration of extreme load cases. If the function of the drive train includes next to the transmission of torque, the support of external loads, a precise knowledge of the design loads is of great importance.
A demonstrative example for the described challenges is the dimensioning of the drive trains of wind turbines. Contrary to the classic design of large-scale power plants, the variable wind conditions and the demands for low weight and low price must be taken into account. The required design loads are taken mostly from simulation software for wind loads like BLADED or FLEX or available measurement results. But also the possibilities of the multibody-system (MBS) simulation are increasingly used in the industry (1).

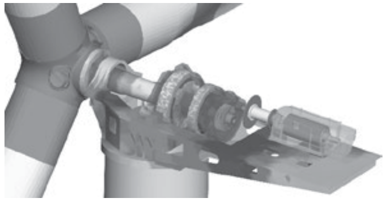

Fig. 1: MBS model of a wind turbine

However, in general, a transformation of the simulated or measured cut loads at the hub or the generator is required, to get the design loads for the drive train components. To determine the safety factors all available time series have to be classified and if necessary extrapolated. The usage of the resulting load spectra depends on the component which has to be dimensioned. According to the valid standards the lifetime of bearings can directly be calculated by using the load spectra. Due to the additional loads, which are leading to an inclination of the planet carrier of the first planetary gear stage, further analysis are necessary (2).

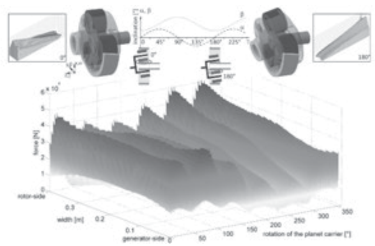

Fig. 2: Load distribution in the gearing in the 1st planetary gear stage of a wind turbine

The possibilities of more detailed analysis will be presented in the paper and the presentation. Especially the challenge of an optimum load distribution in bearings and gearings, influenced by the choice of modifications will be discussed and evaluated (3).

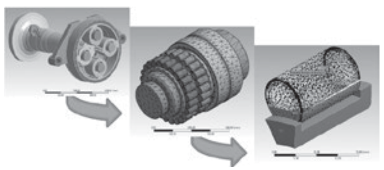

Fig. 3: Reduction of model complexity by submodeling, increase of mesh density

DEWEK 2015 SESSION NO. 14: SIMULATION TURBINE AND COMPONENTS

DEVELOPMENT OF ACTIVE LOAD ALLEVIATION METHODS FOR LARGE WIND TURBINES

A. E. Öngüt[1], S. Flock[2], R. Schelenz[2], G. Jacobs[2], M. Behr[1]

1. Introduction

As the modern horizontal axis wind turbines get larger in rotor diameter, aerodynamic forces impose larger dynamic loads on the turbine components. Active load control mechanisms are considered as ways of reducing these undesired dynamic loads at the source, i.e., at the rotor, thus decreasing the production and maintenance costs as well as preventing possible damage to the turbine.

CATS and IME institutes of RWTH Aachen University collaborate within the framework of project "Aeroelastic Analysis of Large Wind Turbines", financed by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), to develop and evaluate the effectiveness of active load control mechanisms on large wind turbines. Our work focuses on the usage of trailing edge flaps to decrease the blade root bending moments and the peak loads. Aeroelastic CFD simulations are conducted and the reduced-order models that are obtained from the CFD results are used together with the multi-body simulations.

2. Development of Simulation Tools

For this project, we extended our current simulation tools. An aeroelastic solution framework is developed at CATS, which couples different flow solvers with a structural solver. A view of the used CFD model can be seen in Figure 1. Later on, the CFD results are used to develop reduced-order models, which are implemented as input force elements in the multi-body simulation environment.

Fig. 1: CFD model

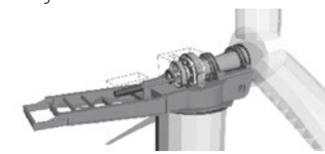

Fig. 2: Multi-body simulation model of the IME 6.0 wind turbine

At IME, a generic 6 MW wind turbine model, which is derived from the publicly available data similar to [1], is developed to analyze the effects of the controller and to evaluate the measures taken for the load alleviation. A multi-body model for the developed turbine is generated (Fig. 2) and used together with the loads supplied by AeroDyn and reduced-order models.

3. References

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NUMERICAL INVESTIGATION ON TOWER EFFECTS FOR DOWNWIND TURBINES

Bernhard Stoevesandt[1], Faraz Habib[1], Bineet Mehra[1], Hamid Rahimi[2], Joachim Peinke[1,2]

1. Introduction

Due to new materials, control strategies and the fact, that noise is offshore not a driving factor, downwind turbines seem go into a revival.
Nevertheless, open questions concerning the main differences to upwind turbines remain. One is on the effect of the tower shadow in the aerodynamics. In load calculations mostly either a wind deficit according to potential theory or empirical models are used [1][2]. Here we investigate, how much this assumption holds using computaional fluid dynamics simulations.

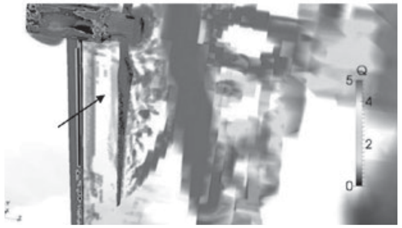

Fig. 1: Vortex structure in the wake of tower and blade of the downwind turbine simulation.

2. Approach

Using the open source tool OpenFOAM-extended 1.6, a simulation of the downwind baseline (B) configuration of the NREL Phase VI experiment has been performed [3]. Steady RANS simulations of the rotor have been used as a precursor simulation. For the tower blade interaction a unsteady RANS simulation was necessary. Therefore a rotor and a stator part of a computational mesh have been created and merged in a common grid. The calculation of the interface was done using the generalized grid interface (GGI) method. The k-omega-SST turbulence model was used for turbulence closure [4]. The calculation used a wall model on the surface with a $24<y+<80$.

3. Results

Comparing the measurement results with the simulation results showed an overall good agreement between the two. Since the turbine was running in stall at this configuration, the tower shadow induced a increase in the suction peak and a change in the impingement point, which is pushed towers the trailing edge on the chord of the blade sections. This triggers a short dynamic stall like phenomenon.

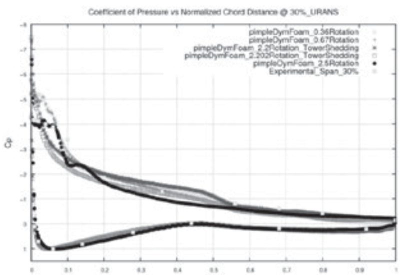

Fig. 2 Pressure distribution at 30% blade span at different rotational positions compared to the average pressure distribution of the experiment.

4. References

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[2] ForWind, Universität Oldenburg, Germany

PARAMETRIC MODEL GENERATION AND AUTOMATED SIZING PROCESS FOR THE ANALYSIS OF WIND TURBINE BLADES

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1. Motivation

In the wind blade design process, simulation tools are used to create and to evaluate the performance of a large number of designs. In order to reduce the effort for the model generation, analysis and evaluation, a design environment for lightweight structures named DELiS with the focus on structural mechanics of aircrafts has been developed [1]. Based on the Common Parametric Aircraft Configuration Schema (CPACS), which is an abstract aircraft namespace, it is possible to create models with variable level of detail, e.g. wings simplified as beam models. With the support of several commercial finite element (FE) solvers many 3rd party applications can be utilized, such as sizing tools. The 3rd party tool Hypersizer is able to size a FE-based structure very efficient. An automated and efficient process based on Hypersizer has been developed originally for aerospace wing designs [2] which is now adapted to wind blade designs. Based on the parametric model generation of DELiS along with the automated sizing the present process is well suited for multi-disciplinary frameworks.

2. Modelling and Sizing process

Fig. 1 illustrates the structural analysis and sizing process. The CPACS dataset is interpreted to create a Python object model in the software DELiS. The parameterization allows it to study various wind blade designs. Based on the object model, DELiS is able to create the input for finite element (FE) tools. The resulting model is used to calculate displacements and stresses as response from external loads. The evaluation of the stresses is done with the commercial software Hypersizer.

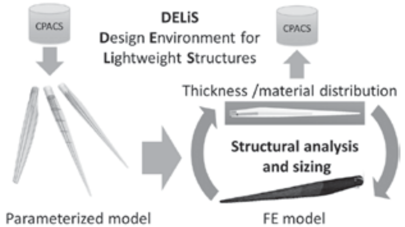

Fig. 1: Structural analysis and sizing process

Hypersizer calculates the laminates and/or thicknesses for different regions and updates the FE model. Iteratively the process creates a sized structure and DELiS writes the thickness and material distribution back to the CPACS dataset.
The publication illustrates the adaption of DELiS to wind turbine blades retaining all functionalities of the aircraft design. An overview of the model generation and model sizing strategy is given. Based on that, an example (DTU reference rotor [3]) of model generation and an automated sizing process is shown with conventional (sandwich) and unconventional (e.g. stringer) designs. The results are compared to the reference results provided by the DTU.

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DEVELOPMENT AND VALIDATION OF COMPREHENSIVE STRUCTURAL ROTORBLADE DESIGN AND SIMULATION TOOL (PMV) WITH FLEXIBLE PRE AND POST PROCESSING INTERFACES

G.Pechlivanoglou, O.Eisele, G. Weinzierl, T. Philippidis, I. Masmanidis*

1. Introduction

PMV is a code implementing various beam theories to calculate sectional characteristics of a given cross section and recover the displacement/strain/stress distribution within the structure.

PMV takes as input the finite element mesh of the cross section including all the details of geometry and material. For complex geometries such as a typical 5MW rotor blade cross section the FE mesh consists of at least 105 elements and the need for a parametric pre-processing tool is necessary. Hence the development of proPMV, a module for creating a rotor blade FE mesh with the minimum effort from the user while keeping track in which component of the cross-section each element belongs to.

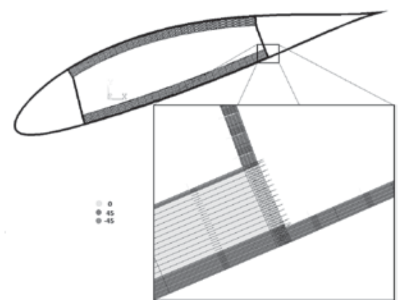

Fig. 1: View of the lamination stacking sequence created by the proPMV module

Although the PMV sectional characteristics output is very straightforward, stress and strain results are stored in a number of files and need further processing to be of any use for the design of a rotor blade. Therefore, the development of metaPMV attends to the need of post-processing of the PMV simulation results. This post processing module also checks the elements for failure using a variety of failure criteria for anisotropic composite materials.

At the current version the limit condition theories of Puck, Tsai-Hill and Max stress are implemented as most effective and popular in the field of wind turbine engineering.

2. Software Validation

The PMV software together with its pre and post processing modules was validated against the THIN code of the University of Patras as well as against ANSYS FE simulations. The rotorblade used for the validation was a 7.5 m rotorblade designed for a 50kW hybrid stall wind turbine. The rotorblade design was characterised by relatively thin airfoils and large chord and twist variation. The conditions of high structural coupling were ideal for the verification of the PMV software against the very successful sectional code THIN of Univ. of Patras as well as the FE software ANSYS.

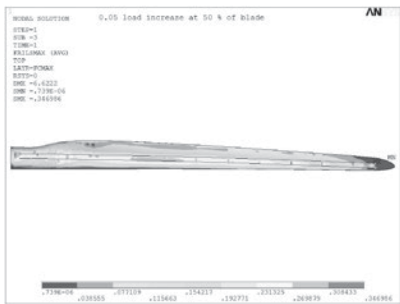

Fig. 2: Comparative case between the results of PMV and ANSYS

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DEWEK 2015

SESSION NO. 15: SIMULATION WIND I

Room 3: Lloyd

MCP: SQUEEZING UNCERTAINTY OUT OF THE LONG-TERM WIND CLIMATE

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1. Uncertainty of Wind Resource Assessment.

The evaluation of the wind resource and estimation of the annual energy production is a highly uncertain process. The largest impact onto the overall uncertainty is given by the uncertainty introduced with the long-term wind conditions.
The application of long-term wind data onto site measurements is often called MCP with it's abbreviatory "C" for correlation. Also, correlation is the focal point of uncertainty analysis.
Here, we show how advanced correlation techniques are able to 1) provide sound uncertainty estimates and 2) considerably reduce the level of uncertainty.

2. Error estimate: MCP

Conventional MCP makes use of linear correlation techniques and combine wind speeds, which have been measured at the site of the future wind park with other sources of long-term wind data.
The advantage of linear correlation is its globally error estimate. Once the error has been determined from a relatively short period of concurrent measurements with long-term wind data, the error remains fixed and may be used to describe uncertainty for any time, also for the future.
The drawback of linear correlation techniques are large errors.
From non-linear correlation techniques or neural networks we know that the error is often small, but it may behave in a non-linear manner: during prediction of the wind the error eventually runs out of control. A situation which is even more worse.

3. Multi-Variate Ensembles Technique

Physics tells us that wind is driven by many different factors: large scale air pressure systems, thermal imbalance in topographic areas or the changes of land coverage are samples for driving factors of the wind. In practical situations one may guess the sources of major impact onto the local wind regimes. And, the long-term wind resource should reflect these multi-variate influence, too.
Meso-scale weather models provide many potential candidates showing impact onto long-term correlation: not only wind speed but also temperature, pressure and a large number of other meteorological parameters are easily available.

4. Reduction of Uncertainty

For this study we make use of the benefits of higher order linear correlations and combine a multitude of parameters from meso-scale weather models by means of adaptive search algorithms. This way, ensembles of long-term winds are generated. Typically 50 – 100 ensemble members are selected out of several thousands of combinations. Each of them fulfil strict error conditions.
Making use of such multi-variate, linear correlation based ensemble technique, the error of the MCP process becomes highly restricted.
We have tested this procedure using the Mini-Wind-Atlas. This atlas provides 30 years of meteorological data at a resolution of 3 km and in the near vicinity of measurement masts. Compared with "free" meso-scale data (MERRA, CFSR, ERA), the uncertainty of long-term correlation was easily reduced by 30% or more.

COMPLEX MICRO SITING OPTIMIZATION: EXPERIMENTAL VALIDATION IN AN ATMOSPHERIC BOUNDARY LAYER WIND TUNNEL

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1. Introduction

Topographic effects on wind are even more important in exploiting wind energy since wind turbines should be located in regions where optimum wind power is obtained. The key aspect for the success of wind farm micrositing in complex areas is the knowledge of the factors that affect the local variability of the wind regarding topography, roughness, mean turbulence intensity and the wakes. For the assessment of the local wind resource in such micrositings the use of the classical models are not reliable to predict wind behavior [1]. In order to identify these special conditions, the physical modeling in a wind tunnel is a possible complementary tool [2]. The research presented in this paper brings the analysis and comparison of the airflow parameters in the generation points in a complex micrositing scale model.

2. The Wind Tunnel Experiment

The tests were performed at the Boundary Layer Wind Tunnel of UFRGS. The wind velocity and the turbulence intensity measurements were taken in twenty different heights, and the measurements used a hot wire anemometry system from Dantec Stream Line.

3. Experimental validation of micrositing

Wind velocity changes in complex terrain are influenced by the surroundings. [3]. Evaluation of energy generated from a wind farm is imperative for feasibility analysis of the power plant. The airflow variables in specific points of the complex micrositing were measured in the experimental study in a wind tunnel, in order to define the parameters profiles in each energy generation point of the micro siting. The array efficiency is directly proportional to the energy output which depends on the distribution of wind speed and the direction in the generation points. Based on these factors, it is necessary to validate the layout in order to allow a minimum interference from topography, roughness, and from the other machines in order to optimize and confirm the energy prediction.

4. Conclusions

The results prove that the experimental validation in a wind tunnel is a promising methodology for quality assessment and the estimation of risks and uncertainties. This tool allows for a quick and reliable improvement of wind energy prediction.

5. References

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IMPROVE THE POWER FORECAST OF A WIND POWER PLANT WITH MATHEMATICAL OPTIMIZATION METHODS

Francesca Jung, Dr. Malte Siefert*, Prof. Dr. Christof Büskens**

Data-based optimization of a very simplified physical model

Due to the uncertainties in the weather forecast and the complexity of the physical relationships, there is no accurate physical model for the power production of a wind power plant. Therefore a method have been designed, which do not need a very complex physical model. Starting from a very simplified physical model instead, measurements are used to find optimal parameters for an included correction function. The physical model considers the wake effects between the turbines and uses a power curve to transform the wind speed to the corresponding power prediction.

Two different methods have been developed:

Inverse Model

The method is called the Inverse Model because the idea is to invert the whole power prediction in a learning phase. The measured power is transformed into a so called inverse wind speed by inverting the physical model. Subsequently, the predicted wind speed is corrected in a way, that it is equal to the inverse wind speed.

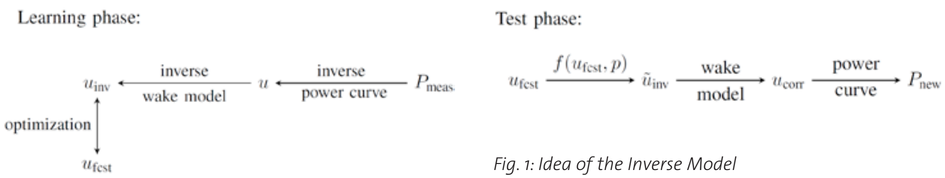

Fig. 1: Idea of the Inverse Model

Direct Model

In the Direct Model the forecast wind speed is corrected such that the power prediction is equal to the measured power of the wind power plant. It is called Direct Model because no inversion of the physical model is necessary.

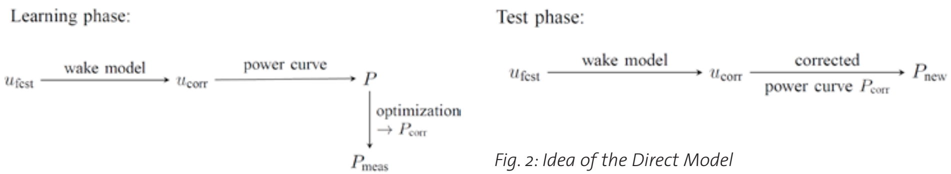

Fig. 2: Idea of the Direct Model

In both models mathematical optimization methods are used for parameter identification on the basis of historical datasets in the learning period. The Inverse Model contains an optimization with regard to the wind speed and the Direct Model contains an optimization with regard to the power. The calculated correction function can be applied on a following test series without historical data.

Different tests have shown that a very simple correction function can be used. A quadratic function results in a halving of the normalised RMSE to 12 % in the test series.
Both models gain similar results and a validation with a neuronal network calculation has shown that these highly simplified methods can obtain results nearly as good as the results from a state of the art method and even better results concerning the laws of physics.
Due to this fact, further research in this direction should be aspired.

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CHARACTERIZATION OF MESOSCALE WIND FLUCTUATIONS IN SPACE AND TIME

Anna Mehrens[1], Lueder von Bremen[1] and Detlev Heinemann[1]

1. Introduction

The amount of produced wind energy at offshore wind farms is rising and this energy is due to the wind characteristics highly fluctuating. The integration of the produced energy into the transmission grid requires high quality wind power predictions. The focus of our work is on mesoscale wind fluctuations with a duration of tens of minutes to several hours (Fig. 1).

For the development of new prediction models, the atmospheric processes and conditions which lead to strong wind fluctuations have to be understood.
The possibility to use remote sensing technologies to measure the wind field in front of a turbine raises the question of the relation between the spatial variability of a wind field and the temporal variability at a fixed location.

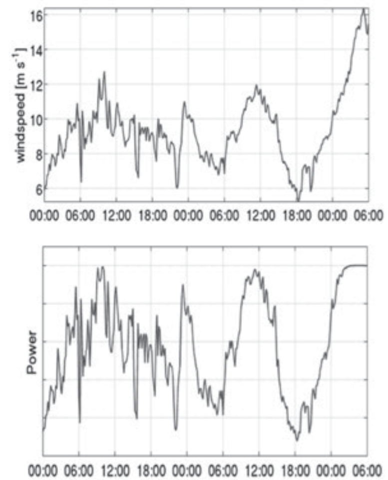

Fig. 1: Example for mesoscale wind fluctuations. 10 min wind speed and calculated Power at the Fino1 met mast in 90 m height (08.-10.02.2009)

2. Dataset

We analyse spatial and temporal wind field data from numerical simulations and measurements at an offshore site with a size of several kilometres. An offshore site was chosen because in an offshore wind park, a large installed power is built on a small geographical area. Thus many turbines are effected by local wind fluctuations and large power fluctuations have been observed.

3. How to measure spatial and temporal mesoscale fluctuations

As a first step, fluctuations due to mesoscale phenomena have to be separated from other time scales. Afterwards a suitable measure for wind fluctuations has to be defined.
The Hilbert-Huang spectrum is a measure which calculates the variability for every single mode of a time series. It has been tested for several offshore measurements [1]. Recent results from the met mast Fino1 confirm the results from Vincent [1] that mesoscale variability is dependent on the season and the wind direction. This suggests that high wind fluctuations occur if cold air flows over warmer water or vice versa. Since the Hilbert-Huang spectrum can only be applied on time series, other measures to characterize spatial mesoscale variability have to be developed.

4. References

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[1] ForWind, Center for Wind Energy Research, University of Oldenburg, Germany (anna.mehrens@forwind.de)

BRAZILIAN WIND INDEXES

Flávio Rosa, Gustavo Haydt*, Juarez Lopes**

1. Introduction

1.1 Motivation

All over the World, wind indexes are used to compare the fluctuations of the wind availability around the long-term average. The Danish Wind Energy Index, the IWET Wind Index and the APREN Wind Index are based on the real production of wind farms. The UK Wind Speed Index is based on wind speed and the ISET Wind Index is based on the wind power density. In Brazil, until 2012, there wasn't any Wind Index disclosed. Therefore, the Energy Research Office (EPE) began publishing the Brazilian Wind Indexes, based on high quality wind measurements on the wind farm reference masts since July 2012. Based on the World experience, EPE calculate two indexes, one using the wind power density (**Energy Index**) and another using the wind expected power production (**Production Index)**. This article describes the methodology and criteria used to calculate the indexes.

1.2 Criteria and database

EPE receives climatic and anemometric data from the wind farms contracted through Brazilian Energy Auctions, located at the Northeast and South of the country. Every wind farm acquires pressure, temperature, humidity, wind speed and direction in a 10 minute base, following the Measnet guidelines.
This study covers 63 wind farms, with a total capacity of 1671 MW and 898 turbines. As Brazil has regions with different wind characteristics, it is necessary to divide the analysis into regions with similar profiles. Using cluster analysis, the country was divided into 3 regions, as seen in Table 1.

Region	States	Masts
Northeast Shore	RN,CE,PI	30
Bahia	BA,PE	24
Rio Grande do Sul	RS	9

Tab. 1: Wind regions in Brazil

2. Power and generation indexes

2.1 Methodology

For the three regions, the indexes are calculated by arithmetic average of the individual results of each wind turbine. In order to have a percent value, a 100% rate was attributed to the average computed from July 2012 to June 2013. The wind power density index (W/m2) is calculated by 0.5ρV3. The wind expected power production index is calculated applying the wind data on the power curve of each turbine.
This methodology was developed with the advice of DEWI[1].

2.2 Results

The Figures below show the Brazilian Wind Indexes at Bahia.

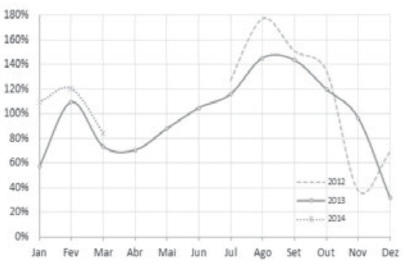

Fig. 1: Energy Index at Bahia

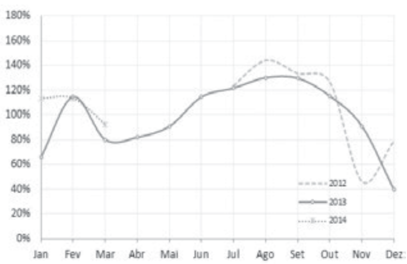

Fig. 2: Production Index at Bahia

3. References

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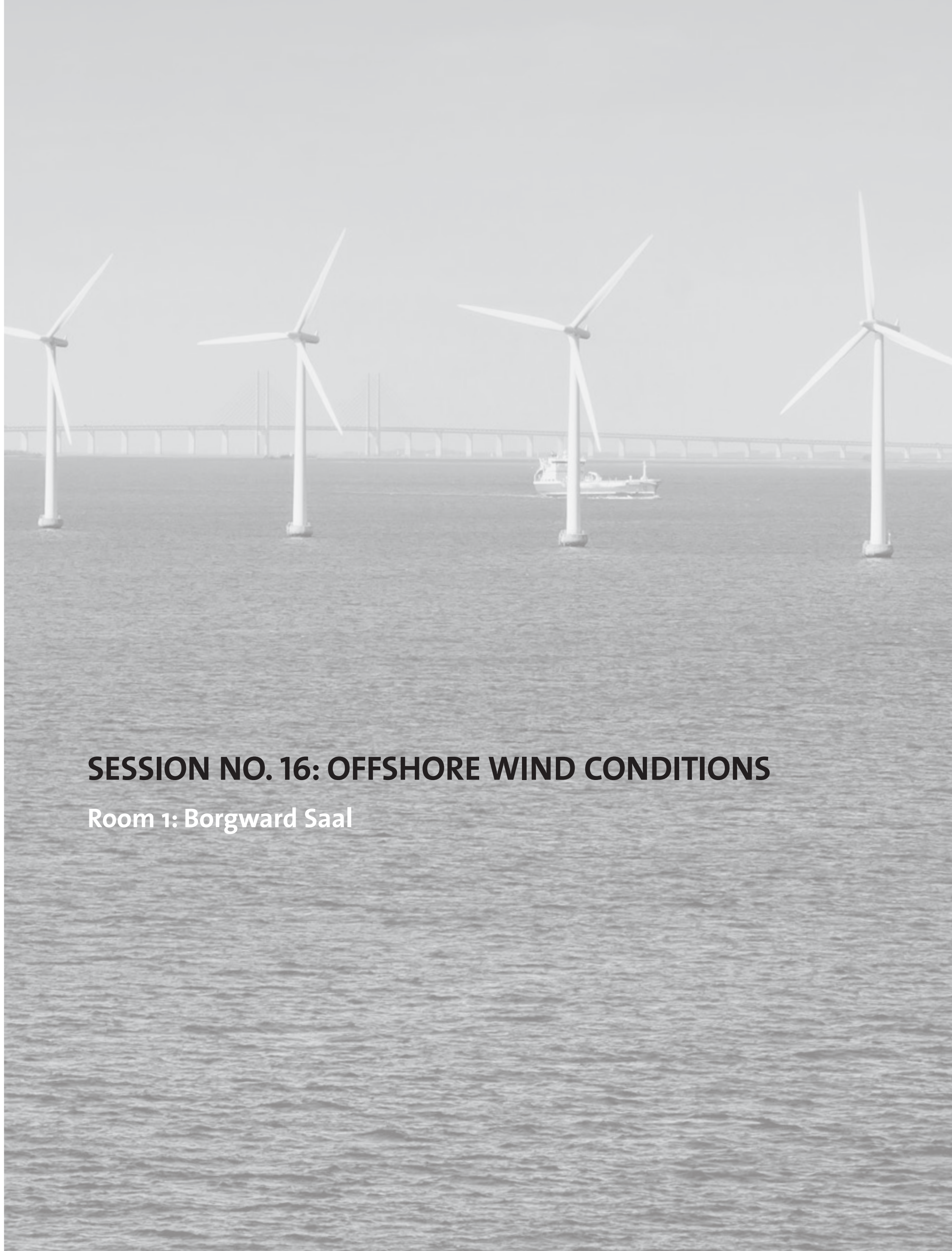

SESSION NO. 16: OFFSHORE WIND CONDITIONS

Room 1: Borgward Saal

STATUS AND OUTLOOK OF THE METEOROLOGICAL LONG-TERM MEASUREMENTS AT FINO1

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1. Introduction

The offshore measurement platform FINO1 has been in operation since September 2003 [1]. During the past 11 years, it has provided valuable long-term measurement data on wind resources and other environmental conditions for several offshore wind farm projects in the North Sea. The meteorological measurements at FINO1 were essentially unaffected by wind farms until the early 2009 when the construction of the first German offshore wind farm "alpha ventus" began [2]. Now in October 2014, already more than 50 wind farms located near FINO1 are in the planning, construction or operation phase (Fig. 1).

Fig. 1: Offshore wind farm projects near the FINO1 measurement platform in the North Sea [3].

2. Update on the meteorological data

Due to the fast development of offshore wind energy in the North Sea, undisturbed wind sectors at FINO1 are being reduced substantially. However, this gives new and unique opportunities to utilise the long-term meteorological measurements when estimating the effects of wind farms on offshore wind conditions, especially the wind speed reduction, wind shear and turbulence intensity [4–5].

A statistical analysis based on the long-term measurements will provide an update on the meteorological conditions at FINO1. The analysis will include a survey on how the nearby wind farms affect the wind conditions depending on their location and layout.

3. References

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ADVANCES IN MONITORING, SIMULATION AND SHORT-TERM FORECASTING AT THE OFFSHORE WIND FARM "ENBW BALTIC 1"

Martin Dörenkämper[1]*, Constantin Junk[1], Lueder von Bremen[1], Gerald Steinfeld[1], Detlev Heinemann[1], Martin Kühn[1].

1. Introduction

The expansion of offshore wind energy will, in the long run, contribute significantly to the renewable electricity production. Most of the planned and also the already connected offshore wind farms will be located in the North and Baltic Seas; the latter with more than 50 planned wind farms with a total capacity of 12 GW [1]. "EnBW Baltic 1", which is located about 15 km North of the Darß-Zingst peninsula, was by the time of commissioning Germany's first commercial offshore wind farm.
Using the example of "EnBW Baltic 1", the aim of the BMU-funded research project »Baltic I«, which is a joint research activity of ForWind-University of Oldenburg in cooperation with SWE-University of Stuttgart and EnBW Erneuerbare Energien, was to improve control strategies of offshore wind farms through local monitoring, simulation and forecasts of wind, power and loading characteristics. Here, we present results of the underlying meteorological research.

2. Wind farm modelling and monitoring

To enhance local wind power monitoring, the SCADA data of the wind farm are investigated to study the impact of wind direction, wind speed and atmospheric stability on the power output of single wind turbines inside the farm and the wind farm itself. The analyses show (among various other aspects) that the coastal distance of the turbines inside the wind farm is playing a crucial role on the power output. Single situations obtained from this analysis are afterwards investigated in more detail by means of Large-Eddy Simulations (LES) with the LES model PALM using detailed parameterizations of the rotor effects on the flow. Due to its triangular shape, the wind farm allows for studying multiple wake situations for simulations of single wind directions.

3. Wind power forecasting

In addition to enhanced wind power monitoring and wind field simulations, accurate deterministic and ensemble forecasts of wind and power are required for the trading and the operational management of wind farms. In contrast to deterministic forecasts, ensemble forecasts provide estimates of the forecast uncertainty to facilitate decision making. We estimate the forecast uncertainty by generating ensemble forecasts either with the analog ensemble method, which requires only deterministic numerical weather predictions as input, or by calibrating existing wind ensemble forecasts from Ensemble Prediction Systems. The latter approach requires a transformation to wind power (e.g. Neural Network) to obtain ensemble wind power forecasts. The difference between a park power curve and individual turbine power curves has been investigated for the EnBW Baltic 1 offshore wind park. We furthermore improve wind power forecasts by combining deterministic and ensemble forecasts from different forecast systems to achieve the most accurate wind power forecast system for intraday and day-ahead forecast horizons.

4. References

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SHADOW EFFECTS IN AN OFFSHORE WIND FARM – POTENTIAL OF VORTEX METHODS FOR WAKE MODELLING

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1. Introduction

Offshore wind turbines in a wind farm often do not operate in free flow conditions depending on the park layout and wind direction. The wake of nearby turbines introduces additional turbulence and impacts structural loads and power production. Semi-empirical wake models exist but are limited in physical representation and application. High fidelity models like CFD require large computational resources and their industrial application, thus, is difficult. An alternative approach based on free vortex methods is applied in this paper to consider both accuracy and computational efficiency.

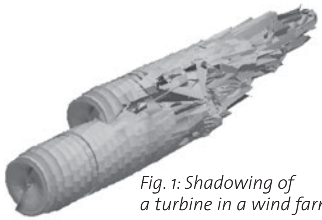

Fig. 1: Shadowing of a turbine in a wind farm

2. Methodology

An offshore reference wind farm based on the layout of the Alpha Ventus test field is used. The wind turbines are modelled on the basis of the NREL 5 MW in the multibody simulation software SIMPACK enabling an integrated aero-servo-hydro-elastic analysis. Aerodynamic loads are computed by means of the free vortex code WInDS based on potential flow theory [1], [2]. The code is written within Matlab, GPU accelerated and coupled to the MBS solver. The wake convects and deforms freely due to the induction of velocity according to the Biot-Savart law. For verification purposes the reference wind farm is setup in the CFD software ANSYS CFX and results are obtained using an actuator disc representation of the turbines.

Fig. 2: Alpha Ventus test field [DOTI]

3. Results

The verification between CFD and free vortex method is shown for the reference wind farm and results are compared for the velocity deficit in the wake and the distributed blade loads. The wind farm is then simulated for various inflow angles using vortex methods. The upwind turbine wake and the resulting shadow effect have a strong influence on the power output of the downstream turbines. Blade loads are analysed showing large fluctuations over the rotor revolution.

4. References

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OFFSHORE WAKE MODEL VALIDATION – METHODOLOGY FOR LINKING MODEL RESULTS AND OPERATIONAL DATA

Niko Mittelmeier[1], Tomas Blodau[1], Martin Kühn[2]

1. Introduction

Accurate estimation of annual energy production (AEP) is essential for wind farm development. Many factors such as wind speed measurement, meso-scale modelling, long term correction, climatic variations, turbine performance and wakes influence the result of the AEP calculation. The EWEA Offshore CREYAP [1] benchmark has shown that, especially for offshore wind farms, wake modelling has one of the biggest impacts on AEP estimation.
Special care must be taken when comparing wake model results to measurements, as large amounts of data are prone to include misleading errors. Additionally, a correct link between the outcome of the model and what has been measured must be established. The latest DTU Fuga wake modelling software [2] has implemented a number of options for linking model results to measurements of wind farm power. These methods can take measurement uncertainties and wake meandering effects into account.

2. Methodology

In this work, we challenge the method of Gaumond [3] who suggests to use a Gaussian averaging of wake model results with a new way of deriving the wind vane standard deviation. Fuga provides Gaussian averaged wind turbine power, stored in two dimensional wake matrices, one dimension for wind speed and the other for wind direction. Wind speed and direction measurements from all nacelle instruments as well as operational data from the wind turbines are combined and by using statistical and analytical methods a free flow hub height wind speed and wind direction is extracted. This analytical free flow wind data is used to interpolate the predicted turbine power from the wake matrices. The Gaussian standard deviation is obtained from the differences of all wind vanes. The results are compared to real measurements from a Senvion large scale offshore wind farm.

3. Results

The new treatment of modelled data with information obtained from the measurements brings the model and the real world results much closer together.
SACDA data from a Senvion large scale offshore wind farm are analysed and compared using the latest features of DTU Fuga wake modelling software.
A guideline, how to tune the Fuga wake model and a discussion on the remaining uncertainty is given. The improvement in AEP calculation accuracy is analysed and highlighted.

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[2] ForWind – University Oldenburg, Germany

VALIDATION OF WIND TURBINE WAKE MODEL RESULTS USING IN-SITU MEASURED WATER PROPERTIES

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1. Introduction

The amount of offshore wind farms in the German Bight increases from year to year. Wind turbines extract energy from the prevailing wind system so the wind speed gets lower in and behind the wind farm, the so-called wake effect. The question, whether wind wakes have any influence on the ocean dynamics, is sparely investigated. Regarding the ambitious plans of Germany, to accomplish 6.500 MW in 2020 with offshore wind energy and the associated areal expansion (Fig. 1), this question should gain more attention.

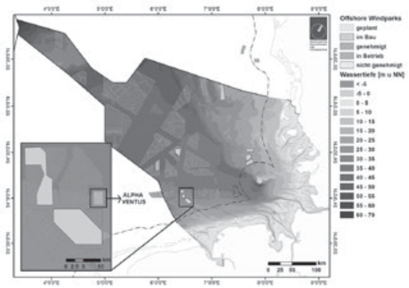

Fig. 1: Wind farms operating (red), under construction (green), planned (red dashed), authorized (light red dashed)

1.1 Background

According to [1] there is an impact of wind wakes on the ocean circulation. By using a reduced gravity model, [1] outlined the response of the ocean to the wind wakes as a divergence at the wind farm. This leads to a dipole structure with up- and downwelling cells. Small changes in the structure of temperature, salinity, oxygen, velocity and surface elevation can occur. An increase in horizontal diffusion was modelled throughout the whole water column, too. The two effects may change the temperature-depending processes, i.e. primary production [2]. Recently, [3] combined an atmosphere and a shallow water model and simulated the effect of a very small wind farm (12 Turbines) on the ocean circulation. The results are that the areal expansion of changes in the ocean circulation, forced by the wind farm, is hundreds of times bigger than the wind farm itself [3].

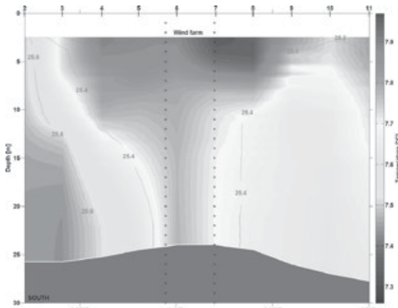

Figure 2: Temperature distribution south of AV, black dots indicate the wind farm position

2. Measurements

Water properties samples around the test site "alpha ventus" (AV) were made. The measurements were taken for a first in situ verification of the model results [3]. The data seem in good accordance with the modelled results, but as this is only a one day snapshot, no reliable information can be gained. More measurements need to be done. As the amount of offshore wind farms increases rapidly, the chance to study the effects of a single wind farm decreases very fast. But to estimate the effects of many wind farms on the ocean circulation, the first step is the observation of the effect of a single wind farm.

3. References

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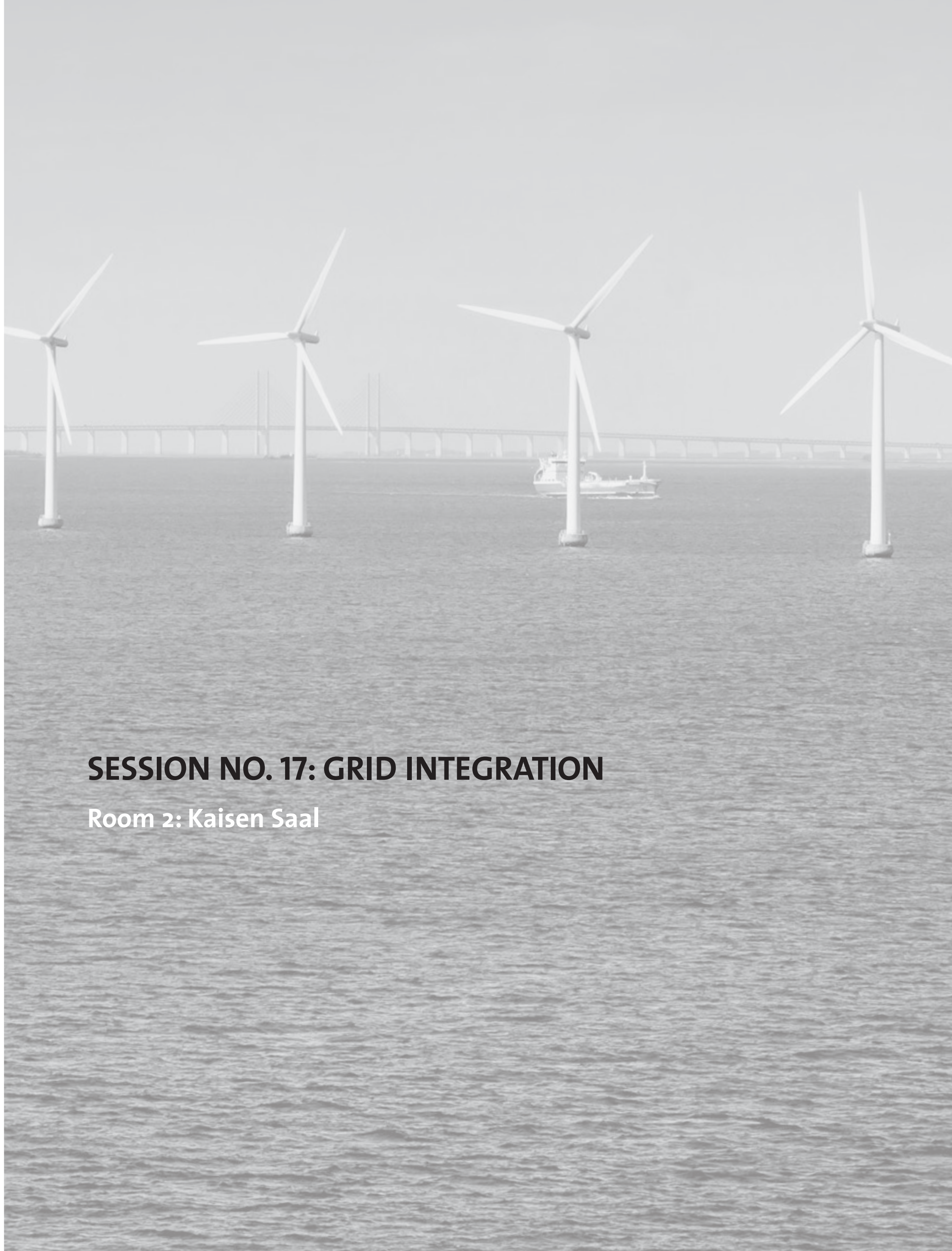

SESSION NO. 17: GRID INTEGRATION

Room 2: Kaisen Saal

A PROCESS TO ENABLE WIND TURBINES TO PROVIDE CONTROL RESERVE AT MINIMUM LOSS OF ENERGY YIELD

V. Marschner, J. Michael*, J. Liersch**

1. Wind turbines for load balancing

1.1 Need for control reserve

The transmission system load is changing constantly subjected by connecting, disconnecting and controlling of electrical devices. The frequency control is performed by the controlled feeding of primary control reserve. The paper examines to which extent wind turbines can provide positive control reserve.

1.2 Utilization of the rotation mass

The additional power is to be obtained from the rotating flywheel mass.
If operating reserve has to be delivered, the equilibrium condition of the power train – the balance between delivered power by the rotor and the taken power by the generator – is temporarily suspended.
A simple physical model is developed that allows drawing conclusions about appropriate concepts by means of a dynamic simulation of the variables rotational speed, torque, power output and rotor power.
In contrast to thermal power plants, the control reserve can be activated instantaneously because the controllability of inverter-driven wind turbines is very high [1]. Thus grid frequency dips can be eliminated at their appearance.

2. Providing control reserve

2.1 Two ways to provide control reserve

Under partial load conditions control power can be fed into the grid for a short time. A part of the rotational energy of the drivetrain is used to increase the feed-in power. Thereby the rotational speed drops so that aerodynamic efficiency decreases and feed-in power is below the initial value after the control process. In this way an unfavourable situation for the transmission system balancing is produced, therefore the paper proposes a modified partial load operation with a higher rotational speed. By providing control reserve the rotor is delayed to the optimum rotational speed so that more rotational energy can be fed in and feed-in power can be increased persistently. However, as the rotor does not operate at optimum speed, a small amount of the energy yield is lost [2].

2.2 Combining both concepts

Finally, the paper shows that a wind farm can combine these two concepts [3]: A part of the wind turbines that works under modified partial load conditions can compensate the decrease of power of the wind turbines working under partial load conditions (Fig. 1). Therefore the requested control reserve is provided and afterwards the original value of feed-in power is maintained.

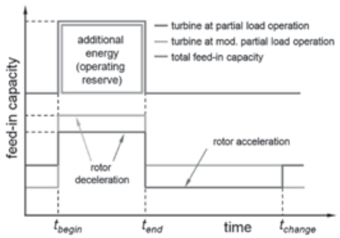

Fig. 1: Idealised process of providing control reserve

3. References

[1] Heier S (2009) Windkraftanlagen, Systemauslegung, Netzintegration und Regelung, 5th edition, Vieweg+Teubner, Wiesbaden
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METHODOLOGY FOR THE EVALUATION OF WIND TURBINE HARMONIC EMISSIONS

Sokratis Tentzerakis, Fritz Santjer, Marcel Bärschneider
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1. Introduction

The accurate knowledge of harmonic current emissions of wind turbines (WTs) is important in networks hosting high wind power levels, especially when harmonic resonance conditions are likely to appear [1]. Although a concrete procedure for the measurement and assessment of WT harmonic currents is already included in the current edition of IEC 61400-21 [2], there is still much work to be done for the effective evaluation of WT harmonic currents, since their actual levels can be strongly influenced by grid characteristics and existing voltage harmonic distortion at the Point of Common Coupling. Towards this direction, an informative methodology for the determination of the grid influence is already included in the relevant German guideline [3] and is under processing within the Working Group of IEC 61400-21.

2. Methodology

In the present paper, a systematic study of WT harmonic current emissions is performed based on actual WT field measurements. For a more compre-hensive evaluation, two variable speed WT types with different electrical design are examined, employing particular harmonic spectrum patterns. The one WT is equipped with a doubly fed asynchronous generator while the second with a permanent magnet generator.
The study begins with the detailed assessment of the harmonic current phase angles, a topic which can provide useful information regarding the possible grid influence though not exhaustively examined up to now. The calculated data distributions are presented for selected averaging times and harmonic orders, in the low and high frequency range, while the prevailing phase angle index is derived. The calculated phase angles are also directly exploited for the estimation of the active and reactive power flows for each harmonic order, which in turn is considered for the determination of the grid background noise levels.
For better understanding of the variation of WT harmonic currents, it is essential to calculate their values with averaging times other than 10 minutes. In this study, the harmonic currents at lower averaging times are calculated (3 s and 10 cycles) and the relevant data distributions and statistical characteristics are derived (mean, minimum and maximum values, standard deviation and 95-percentile).
The present work closes with an examination of the effect of the WT operating point on the harmonic emission levels for particular harmonic orders, while an assessment of the slip-related low-order inter-harmonics of DFIG WTs is included, to serve as a basis for a more accurate evaluation of the harmonic emissions of these WT types.

3. Conclusions

The results of the study show that, using a systematic methodology, it is possible to have a more effective evaluation of WT harmonic currents and a more accurate assessment of the possible influence of the existing grid harmonic distortion.

4. References

[1] Fritz Santjer, Jens Herbrandt, "Harmonic current emission of wind farms exceeding the limiting values", DEWEK 2010.
[2] IEC 61400-21, "Measurement and assessment of power quality characteristics of grid connected wind turbines", Edition 2, 2008.
[3] FGW – TR3, Determination of electrical characteristics of power generating units and systems connected to MV, HV and EHV grids, Rev. 23, 2013.

ASPECTS FOR IMPROVEMENT OF MEASUREMENT AND ASSESSMENT PROCEDURES OF HARMONIC EMISSION OF WIND POWER PLANTS

Fritz Santjer, Bernd Weise*, Tina Pausch**, Johannes Brombach**

1. Abstract

Harmonic emission of wind and photovoltaic (PV) power plants is one of the main aspects for their grid integration related to power quality. In this paper the authors represent findings and intermediate results of the FGW[1] working group for harmonics (German: AG Oberschwingungen) which is dealing with the improvement of measurement and assessment procedures of the harmonic emission of single generating units, like wind turbines as well as wind and PV power plants.

The main aspects for investigations are:

- Background noise in the grids, which influence the harmonic emission measurements of single generating units and power plants
- Measurement procedures for single generating units and for power plants, like [1] or [2]
- Requirements on test bench and field measurements
- Harmonic behaviour of components of the power plant internal grid, like transformers
- Harmonic characteristics of voltage and current transducers, used for harmonic measurements
- Summation laws to calculate the harmonic emission of a wind power plant based on the emission of single generating units
- Analysis methods, like the phase angle of harmonic currents and voltages, prevailing ratio, direction of power flow
- Resonance effects and impedances in electrical grids
- Assessment procedures in grid codes
- Modelling of the electrical behaviour of single generating units, like wind turbines and PV inverters with respect to harmonics (harmonic models)
- Validation of harmonic models.

This paper will deal with the objectives of the working group. After an introductory illustration of the issues related to harmonics in the nowadays common practice, approaches for improvements as discussed in the FGW working group as well as intermediate results and performed investigations are presented:

- Procedures and examples for the detection of background noise
- New analysis methods like the prevailing angle and ratio
- Aspects for harmonic models and for model validation
- Investigation and example of summation laws

2. References

[1] IEC 61400-21, "Measurement and assessment of power quality characteristics of grid connected wind turbines", Edition 2, 2008.
[2] FGW – TR3, Determination of electrical characteristics of power generating units and systems connected to MV, HV and EHV grids, Rev. 23, 2013.

FGW Working group Harmonics (AG Oberschwingungen)	
Members: • Manufacturers of wind turbines and PV inverters • Grid operators • Measurement institutes • Certification bodies • Universities • Consultants	**Chairman:** Fritz Santjer, DEWI GmbH **Chairman of Subgroup Harmonic Models:** Bernd Weise, DIgSILENT GmbH **FGW representatives:** Jens Rauch Tina Pausch Johannes Brombach

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TRADE-OFF BETWEEN STORAGE AND INTER-COUNTRY TRANSMISSION NEEDS IN AN EUROPEAN ENERGY SYSTEM DOMINATED BY RENEWABLE SOURCES

Alexander Kies[1,2], Lüder von Bremen[1,2], Kabitri Nag[2], Elke Lorenz[2] and Detlev Heinemann[1,2]

1. Introduction

1.1 Background

A future European energy system based mainly on renewable generation will have large contributions from wind and solar energy.
These sources have highly fluctuating feed-in profiles in dependency of the prevailing weather conditions. To overcome the mismatch between these feed-in profiles and the consumption several methods have been investigated like the seasonal optimal mix between wind and Photovoltaics [1] or excess generation [2].
In this work we are investigating the interplay of storage and transmission needs in the European energy system in dependency of the generation mix.

1.2 Method

We have used a large weather data set with a spatial resolution of 7 x 7 km and a hourly temporal resolution to calculate feed-in of different renewable sources like wind onshore, offshore, Photovoltaics and hydro for 34 European countries.
The calculations cover the time-period from 2003 to 2012.
For transmission grid investigations a simplified DC-model has been implemented.
The mix between different renewable generation sources has been investigated with the objective to minimize the residual load and its effect on storage and the transmission grid.

2. Results

2.1 Previous results

Previous works that will be included have shown that transmission has the potential to reduce storage needs in a 100%-renewable European energy system by around 50%. This is true if feed-in is contributed by wind and Pv alone.
Hydro power today contributes between 10 and 15% to the European electricity generation. If hydro is taken into account besides wind and pv storage needs can further be reduced by another 50% with unlimited transmission capacities between countries.

2.2 New results

To reduce storage needs considerably additional inter-country transmission extensions are necessary.
We will show and discuss how the transmission needs are influenced by the target to reduce storage needs and discuss the trade-off between minimizing storage and increasing transmission needs with respect to the optimal mix between wind onshore, offshore, Photovoltaics and hydro in a fully renewable European energy system.

The work is part of the RESTORE 2050
project (BMBF) that investigates the requirements for cross-country grid extensions and usage of storage technologies and capacities.

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[2] D. Heide et. al, Reduced storage and balancing needs in a fully renewable European power system with excess wind and solar power generation Renewable Energy 36 (2011) 2515-2513, March, 2011.

[1] ForWind, Center for Wind Energy Research, Oldenburg, Germany;
[2] Institute of Physics, University of Oldenburg, Oldenburg, Germany; alexander.kies@uni-oldenburg.de

RELIABILITY INDEXES OF WIND FARMS IN BRAZIL

Flávio Rosa, Gustavo Haydt*, Juarez Lopes**

1. Introduction

1.1 Motivation

The use of wind energy in Brazil has been gaining attention since the energy auction promoted by the Ministry of Mines and Energy in 2009. However, the benefit of wind farms to meet the peak load is still not recognized, either because the resource can't be controlled or due to the lack of adequate long-term wind data to evaluate this issue.

1.2 AMA System

Since 2011, the Energy Research Office has been operating the AMA System, a database to store climatological and anemometric measurements acquired at the wind farms contracted through Brazilian Energy Auctions.
This study uses data from July 2012 to June 2013, measured at 54 wind farms in the Brazilian Northeast, with a total capacity of 1464 MW and 794 turbines.
Using the wind power production and the load curve of the region it was developed a probabilistic model to evaluate the reliability of the wind farms through monthly indexes.

2. Reliability Indexes

2.1 Methodology

This study uses the analytical method of frequency and duration [1] to evaluate the power system reliability. This test system has only wind power plants and the load. Besides the traditional reliability indexes (LOLP, LOLF, LOLD, MTBF, EPNS and EENS), it is also calculated an indicator called "guaranteed power with 5% of risk" (GP95%).

2.2 Case study

To evaluate the effects of integrating wind farms with different wind profiles, the indexes are calculated for five cases:
1) all farms;
2) only farms on the coast;
3) only farms at the interior;
4) just one farm on the interior;
5) just one farm at the coast.

The scenarios demonstrated a variation in reliability over the months and the contribution of the geographical diversity on the results. For example, Table 1 shows the results regarding the GP95% index.

CASE	2012					
	Jul	Aug	Sep	Oct	Nov	Dec
1	38%	47%	42%	43%	20%	27%
2	39%	49%	45%	42%	24%	31%
3	7%	16%	9%	10%	0%	5%
4	5%	12%	5%	6%	0%	0%
5	20%	21%	20%	22%	17%	17%

CASE	2013					
	Jan	Feb	Mar	Apr	May	Jun
1	17%	36%	14%	11%	19%	20%
2	19%	23%	14%	7%	21%	16%
3	0%	9%	0%	0%	1%	8%
4	0%	6%	0%	0%	0%	5%
5	10%	10%	10%	5%	9%	3%

Tab. 1:GP95% index

The reliability indexes provide a basis for establishing criteria to analyse the contribution of wind resource to the power system. Also, they can be used for a better knowledge of the real risks and benefits when integrating wind power on a large scale.

3. References

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*EPE, Rio de Janeiro, Brazil, +55-21-3512-3149, gustavo.souza@epe.gov.br;
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SESSION NO. 18: SIMULATION WIND II

Room 3: Lloyd

CHOICE OF WIND FLOW MODELS FOR ENERGY YIELD ASSESSMENT

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1. Introduction

Linear models remain the most accepted standard for micro-scale modeling as they provide robust and fast answers to decision-makers, and have been the standard for a long period of time. However, the industry has been working on improving CFD models over the past decade; this technology is now more accessible as models got easier to use and as computer power increased over the years. Similarly the use of mesoscale and coupled models is now more widespread across the community.
We propose to compare performance and added-value of linear, CFD, mesoscale, and mesoscale-coupled CFD models.

2. Models description

The models used for comparison are the MS3DJH linear model [1] embedded within the Windfarm software, a RANS CFD code [2], the WRF mesoscale model [3], and a last-generation mesoscale-coupled CFD code [4].

3. Methodology

All four models are run on a set of wind farm sites on which measurements from two masts or more are available. On each site one set of measurements is provided to the model for calibration/forcing, while others are used for error computation.

Variables used for comparison are wind speed, wind shear, and turbulence intensity.

4. Results

Figure 1 provides an example of the types of results that will be provided. Results shown here are only preliminary. In particular the number of mast pairs used (11 on Figure 1) will be significantly enlarged.

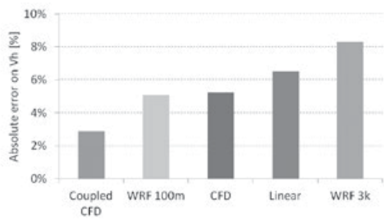

Fig. 1: Preliminary results.

5. Discussion

The figures provided for each model will be analyzed in the light of their various added values for wind project developers versus associated running time and costs.

6. References

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SENSITIVITY OF ANALYTICAL WAKE MODELS TO PARAMETER SETTINGS

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1. Introduction

Successful site assessment consists of the correct estimation of wind speed distribution in the park areas as well as planning an optimized park layout in terms of internal wakes. Even though wind resource assessment tools might do a good job in describing the wind speed it is still a challenge to correct the annual energy production (AEP) to take into account wake effects.
Nowadays, challenges come from the combination of growing wind turbines with larger rotor diameters, more powerful wakes and the requirements of placing as many turbines as possible in limited planning areas to maximize park output.
Within this study, the performance of the most common wake models is evaluated in terms of their sensitivity to different parameter settings and by validation against high resolution production data of a windpark with changing number of turbines during the years.

2. Approach

Several analytical wake models are used in the AEP calculation today and every commercial wind resource assessment tool has found its own way to implement them. Every wake model has parameters which can be set either as constant standard values or depending on the surrounding conditions and those can influence the AEP calculation considerably.
Depending on the individual park situation, the relevant parameters as the wake decay factor, the roughness length at the turbine etc. can be taken from estimated standard conditions or from real measurement data.

Further wake model specific condition as the sub cycles in the wake calculation, turbulence parameterization and model constants can be chosen.

A commercial CFD tool and the common WAsP model will be used to calculate the change in AEP when varying those parameters to quantify the sensitivity of the output to different parameters.
The calculated AEP values will be compared to real production to get an idea which parameter settings might be suitable to describe the AEP as good as possible and which wake model comes closest to predict the AEP of existing wind farms.

3. Results

In this presentation we show that even within one wake model, the choice of parameters can have considerable influence on AEP output and we quantify the results to learn more about the different analytical wake models and how they are implemented in wind resource assessment tools.

4. References

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[2] Katic, I., Højstrup, J., Jensen, N.O.: A Simple Model for Cluster Efficiency." EWEC Proceedings, 7-9 October 1986, Rome, Italy.
[3] Ishihara, T., Yamaguchi, A., Fujino, Y.: Development of a New Wake Model Based on a Wind Tunnel Experiment. Global Wind Power 2004.

TOPOGRAPHIC EFFECTS ON THE WAKES OF A LARGE WIND FARM

J. Caldas*, E. L. Zaparoli*, C. Y. Chang**, C. Peralta**, J. Schmidt** and B. Stoevesandt**

1. Introduction

Large onshore wind farms are usually located in windy and highly mountainous terrain. Sudden changes in wind direction and strong turbulence develops easily on such situations, making a precise wind assessment for wind turbine siting a very challenging task. Traditional long term measurement campaigns are constrained by elevated costs, while standard engineering wake models (Park [1], Ainslie [2] and extensions of these [3]) ignore the effects of the orography. For these reasons it is common to recur to computational fluid dynamics (CFD) methods for performing wind site assessment in locations with a very complex orography. The open source package OpenFOAM (OF) is now widely used by a number of institutions and commercial enterprises around the world for modelling the atmospheric boundary layer (ABL) in complex terrain[4,5].

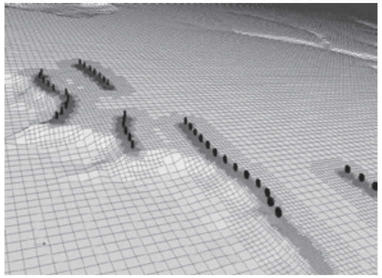

Fig. 1: Unstructured mesh of the wind farm.

2. This study

In this contribution, we use OF-based solvers and utilities to perform a wind assessment of a large wind farm to be located in a plateau in Brazil.
The planned wind farm consists of 105 Gamesa G97 wind turbines (see Fig. 1). We simulate numerically a neutral ABL by solving the RANS equations using the standard k-epsilon model and modified version of this model recently proposed by [6] and [7] to improve wake predictions. The wind turbines are modelled as uniformly loaded actuator disks (Fig. 2). The mesh is constructed using an in-house OpenFOAM-based unstructured mesher, which includes refinement utilities for the sections of the mesh containing the actuator disks.

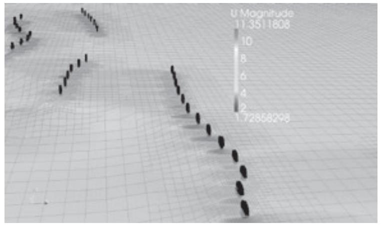

Fig. 2: Wind turbine wakes.

We study two of the prevailing wind directions at the site: East and ESE (120 deg) and calculate the annual energy production (AEP) and compare our results with standard engineering wake models [1]-[3]. Additionally, we estimate the minimum distance between turbines as a function of the wind direction.

3. References

[1] Katic, Hojstrup J, and Jensen N.O. A Simple Model for Cluster Efficiency, European Wind Energy Association, Conference and Exhibition, 7-9 October 1986, Rome, Italy.
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EXTENSIVE VERIFICATON OF WRF MESOSCALE MODEL DOWNSCALING

Jens Kampmeyer[1], Julia Bethke[1], Heinz-Theo Mengelkamp[1], Doron Callies[2]

1. Content

1.1 Model Data

The mass of commonly used wind data for site assessment grows rapidly. But the detailed verification in a broad range is rare. Here a high resolution WRF [1] mesoscale data set was created and verified with various measurements in Germany and Poland.

1.2 Measurement data

Regional distributed wind data with 120 high quality and certified anemometers, shared on 40 measurement masts within a height range from 30 up to 200 m, are prepared for verification. With respect to these measurements the MERRA [2] Reanalysis data turn out to be the best choice for further refinement. So we use the WRF mesoscale model to scale the MERRA-data down to 3 km horizontal resolution.

2. Verification

2.1 Methods

In this study we point out the performance of the WRF mesoscale model in a broad range of environments. The following verification methods on hourly time based wind data locate benefits and handicaps of the model in rotor affected heights. Vertical and diurnal profiles (Fig. 1) show the models performance in shear and atmospheric stability. Frequency distributions of speed and direction, quantile-quantile diagrams inform about the added scales to the forcing data. The basic skill parameters correlation, mean absolute error and bias are analysed in annual cycles and present the seasonal deviations.

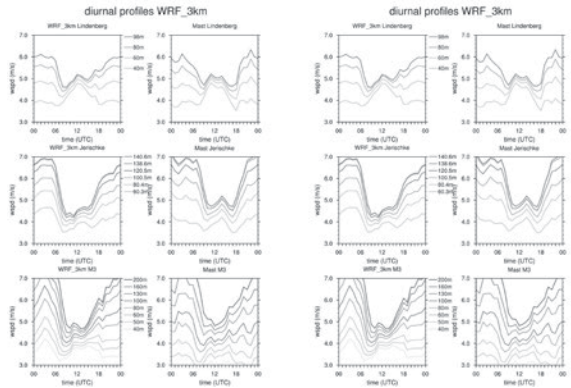

Fig. 1: Diurnal profiles for Model and Measurement.

2.2 Conclusions

Due to the large data base of wind measurements conducted in different surroundings, it was possible to conduct a meaningful verification of modeled wind data with 3 km grid resolution for Germany and Poland. The resulting skill parameters show the models accuracy to wind estimation purposes on sites with differing complexity and challenges.

3. References

[1] Skamarock, et al., A description of the Advanced Research WRF version 3. NCAR Tech. Note 2008. NCAR/TN-475+STR, 113 pp.
[2] Rienecker, M. M., Suarez, M. J., Gelaro, R., Todling, R., Bacmeister, J., et al. MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications. J. Climate 2011

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LARGE EDDY SIMULATION OF THE FLOW AROUND A WIND TURBINE BLADE

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1. Introduction

To efficiently exploit the installation space and to reduce maintenance and installation costs, wind turbines are more and more clustered in large wind farms. Therefore, a substantial number of wind turbines are located in the wake of upstream wind turbines. This results in: a reduction of the power production because of the velocity defect and increased dynamic loads due to enhanced turbulence intensity in the incoming flow field.
For the analysis of the power losses and the dynamic loads of a blade, it is therefore crucial to accurately predict the wake. The tip and hub vortex systems have a significant effect on the wake development since such vortex systems generated by the wind turbine blade and nacelle cause high velocity gradients and large turbulent intensities. This is why, the vortex dynamics and stability of such vortex systems are to be investigated.
To analyze the development of the wake downstream of a turbine blade including the vortex system, a block-structured body-fitted mesh is generated to resolve the flow field. Simulation methods based on Reynolds averaged Navier-Stokes equations are widely used for wind turbine simulations, but they cannot resolve the details of tip and hub vortices accurately. Therefore, large-eddy simulations (LES) are conducted in this paper.

2. Numerical Method

The turbulent flow around the wind turbine blade at chord Reynolds number Rec=300,000 are performed is investigated by a finite-volume method, the details of which are described in [2,3]. The solution focuses on the resolution of the tip and hub region, where the vortex system is formed. The simulation is performed in a rotational frame of reference on a body-fitted grid around the blade. Periodic boundary conditions are used in the circumferential direction such that only one of the three blades needs to be resolved in an azimuthal sector with 120-degrees.

3. Results

The results show the dependence of the stability of the vortex system on frequency dependent perturbations. In Fig. 1, no perturbation is used for the helical vortex system resulting in a stable vortex development (Fig.1a). If, however, perturbations are imposed the vortex systems become unstable. At high-frequency perturbations short-wave instability (Fig. 1b) is observed that occurs further upstream flow the instability at a low-frequency perturbations (Fig. 1c).
To simulate the flow field around the wind turbine blade, a mesh with a special topology satisfying the periodicity conditions has been generated. The simulation will be validated by comparing the numerical results with experimental data. Furthermore, the characteristics of the wake flow in particular the vortex system will be analyzed.

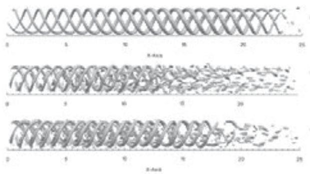

Fig. 1: LES of helical vortex system without (a) and with perturbations (b, c)

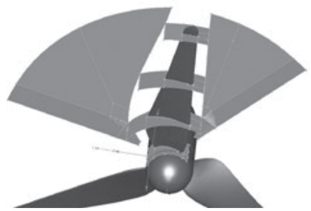

Fig. 2: LES mesh for the flow around the blade with 200 million mesh points

4. References

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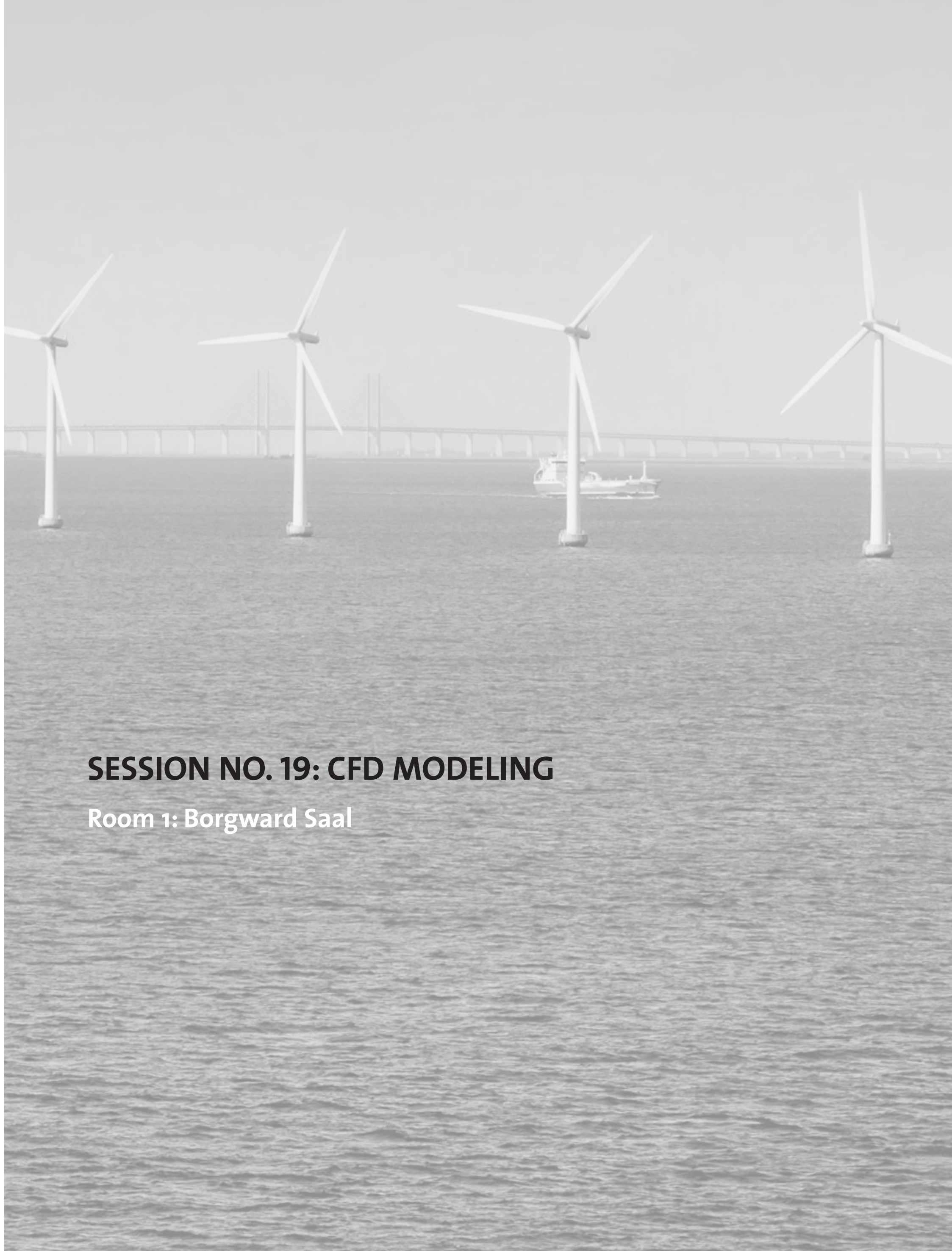

SESSION NO. 19: CFD MODELING

Room 1: Borgward Saal

WAKE MODELLING OF AN OFFSHORE WIND FARM USING OPENFOAM

A. Javaheri, B. Cañadillas
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1. Introduction

Undoubtedly development of the wind energy as one of the primary clean sources is an inevitable way to achieve sustainable and green energy supply. In this respect, offshore wind farms are rapidly getting bigger. Wind turbines operating in a wind farm will be exposed to the wake influence of neighboring turbines. Wake behind a wind turbine leads to a reduction of the mean wind speed and an increase of turbulence level. Therefore in order to design an optimum layout for a wind farm, the evaluation of the wind turbine wake effect is essential because it leads to high fatigue, which reduces significantly the turbine lifetime, and decreases the energy extraction for the downstream wind turbines. There are different approaches to model the wind turbine wakes, from analytical models to three-dimensional CFD rotor modeling. Today, most of the site assessment CFD simulations are performed using commercial packages like PHOENICS [1]. As an alternative to those commercial packages, the open source CFD toolbox OpenFOAM [2] is getting more important. Due to the open source concept, the toolbox license is free of charge and the free access to its source codes which gives the ability for self-enhancing and extending the program, makes Open-FOAM very interesting for wind farm developers. For this work, OpenFOAM 2.1.1 has been used and all the simulations were run in a workstation of 16 GB RAM quad core Intel 3.4 GHz processor [3] and conducted through the solver simpleFoam. Thrust is the only force applied on the wind flow by the actuator disks and the atmospheric stratification is assumed to be neutral throughout the project.

2. Summery

The aim of this study is to test the availability of the Computational Fluid Dynamics (CFD) tool OpenFOAM to estimate offshore wind turbine wakes. For this purpose, required libraries of the tool are investigated and developed.
In this simplified CFD wake model, wind turbines are modeled by an actuator disk which applies an axial momentum source on the wind flow. The uniform and radial load distributions on the actuator disk are assessed and the radial actuator disk library is modified. In addition, two various groups of coefficients of the standard k- turbulence model and afterwards an additional turbulence model are checked. In each part of these test cases, the results are evaluated using measurement data of the Sexbierum wind turbine experiment [4]. Finally, Alpha Ventus wind farm [5] is simulated for certain wind directions and the results are validated using measurement data from the offshore mast FINO1 [6] in terms of wind speed deficit and turbulence intensity and compared with a reference simulation obtained by the commercial CFD package PHOENICS.

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DETERMINING OFFSHORE MAST SHADOW CORRECTION FUNCTIONS WITH CFD METHODS

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1. Introduction

One of the most important parameters to determine the profitability of an offshore wind farm project is wind speed. A standard way to measure wind speeds, are anemometers mounted on meteorological masts. Standards and Best Practice reports like the IEA Recommendation 11 [1] recommend boom lengths and other details for sensor mountings in order to minimize the systematic bias on the measured wind speeds as a result of the flow distortion generated by the mast itself. In offshore environments massive mast structures like FINO1 are commonly used, which cannot follow the IEA Recommendation because it is not possible to construct booms of sufficient lengths due to boom vibrations or logistic issues. Therefore mast shadows, partial or total, at certain inflow directions are an important source of error when dealing with offshore wind measurements. This error has to be investigated and corrected carefully.
In this study the mast effect on three sensor heights of an offshore lattice mast (FINO1) is estimated with CFD methods and mast corrections are evaluated.

2. Methodology

A 3D model of FINO1 was build and split up in three 10 m long segments around the measuring heights 71.5 m LAT, 81.5 m LAT and 91.5 m LAT. These models were calculated with OpenFoam® for several inflow directions and the resulting wind speeds at the boom tips were compared to the UAM correction functions found by [2].

3. Results

As results we are gaining information about:

- Wind speed profiles and shadows propagating from each small steel part of the structure. This can be used to optimize mast designs.
- Calculated wind speed and direction data at each sensor position, which can be used to derivate functions to correct wind speeds and directions for different inflow directions. This data is in good accordance to former measured mast effects.

4. Acknowledgements

FINO1 platform is part of the FINO project. The CFD calculations are performed within the research project FINO Wind. Both projects are funded by the Federal Ministry for Enviornment, Nature and Nuclear Safety (BMU)

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AN EXTENSIVE VALIDATION OF CFD FLOW MODELLING

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1. Summary

We present here the results of a three-year validation effort, analysing the results of flow modelling conducted on 200 commercial wind farm sites from 2012 to 2014, using DNV GL's Computational Fluid Dynamics (CFD) model as well as WAsP. Averaged across all sites, the error on mean wind speed (MWS) was lower with CFD (3.5%) than with the linear model WAsP (4.5%), indicating that, when applied correctly, CFD can consistently improve wind speed predictions and reduce uncertainty in energy production assessments.

2. Introduction

For those trying to predict the future energy output of wind farms, understanding spatial wind flow patterns has long presented a fundamental challenge. Acknowledging that wind flow modelling is one of the largest sources of uncertainty in a wind resource assessment, DNV GL continuously validates its in-house CFD model of wind flow over terrain. Accurate microscale flow modelling results in better wind farm designs, lower uncertainty, better project returns and ultimately lowers the cost of energy. In order to better predict the flow over complex terrain, forested sites or in thermally stable conditions, DNV GL developed an in house model powered by STAR-CCM+, a state of art CFD model, solving the Reynolds-Averaged Navier-Stokes (RANS) equations with a two-equation turbulence closure. CFD models have long promised to increase accuracy compared to traditional linear models, but previously published validations have generally rested on small sample sizes. We present here a validation of a different character, with 200 diverse sites and over 3000 mast pairs; a dataset that dwarves in size that of any CFD validation published by other parties to date.

3. Approach

DNV GL used its CFD model as well as the WAsP linear model to calculate the mean wind speeds at the mast locations. We compared the calculated and measured mean wind speeds on all available data for sites equipped with at least two masts, in different locations spread across five continents, with a wide range of terrain types, ground covers as well as atmospheric conditions.

4. Results

CFD consistently yielded a smaller error on MWS than WAsP at over two thirds of the investigated sites. Averaged over all sites, CFD analyses yielded a smaller error (3.5%) than WAsP (4.5%). CFD also further distanced itself from WAsP in 2014 (CFD 3.1% vs. WAsP 4.1%), compared to 2012-2013 (CFD 3.9% vs. WAsP 4.8%). The absolute errors were smaller in 2014 for both CFD and WAsP, indicating that CFD can also add value at more moderately complex sites [1].

5. Conclusion

Based on this three-year validation, CFD modelling can consistently reduce flow modelling error, increase accuracy and combined with the engineering expertise developed at DNV GL, add significant value to energy production assessments. For a typical energy assessment, the reduction in energy uncertainty attributable to CFD would be around 2%.

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SESSION NO. 19: CFD MODELING DEWEK 2015

STUDYING THE EFFECT OF BLADE DEFLECTIONS ON THE AERODYNAMIC PERFORMANCE OF WIND TURBINE BLADES USING OPENFOAM

B. Dose, B. Stoevesandt*, J. Peinke**

1. Introduction

Modern wind turbine rotor blades are designed increasingly large and flexible. This structural flexibility represents a problem for the field of Computational Fluid Dynamics (CFD), which is used for accurate load calculations and detailed investigations of rotor aerodynamics. As the blade geometries within CFD simulations are considered stiff, the effect of blade deflections caused by aerodynamic loads cannot be captured by the "common" CFD approach. The coupling of both flow and structural solvers can solve this problem and enables detailed investigations of flexible wind turbine blades.

2. Method

To capture the effect of wind turbine blade deflections within CFD simulations we implemented a new Finite Element (FE) solver into the open source CFD code OpenFOAM [1]. Using an advanced beam element formulation based on the Geometrically Exact Beam Theory (GEBT), originally proposed by Simo [2], the structural model can capture geometric non-linearities such as large deformations. Coupled with steady-state RANS solvers of the OpenFOAM package, the new framework represents a powerful tool for aerodynamic investigations.

3. Results

We investigated the effect of blade deflections on the aerodynamic performance of the NREL 5 MW reference wind turbine [3]. For different wind speeds, we evaluated aerodynamic key parameters like pressure coefficients, torque and thrust. Figure 1 shows deflected blades of the NREL 5 MW wind turbine.

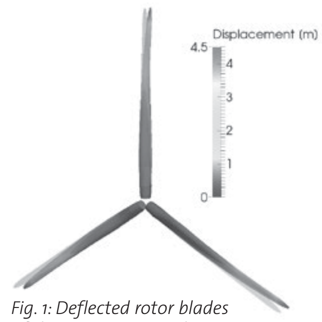

Fig. 1: Deflected rotor blades of the NREL 5 MW turbine

4. Conclusion

We developed a new framework for the steady-state CFD investigation of flexible wind turbine blades. The coupled tool allows an efficient CFD investigation of large, flexible wind turbine blades.

5. References

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HOW MUCH DO CFD MODELS IMPROVE THE ACCURACY OF THE FLOW MODELLING?

B. Jimenez*, D. Rimpl* and K. Moennich*

1. Abstract

The Annual Energy Production (AEP) estimation for a wind farm is a crucial step in the planning phase of new wind farm projects. More and more wind farms are built in highly complex terrain for which the traditional tools for flow field calculations, like the industry standard WAsP 4 developed by DTU (Risø), are beyond their application limits. It is well known that such linear flow models cannot resolve flow detachment and recirculation, which become increasingly important in complex terrain analysis and evident in the Bolund blind comparison results 5.

The ability of the Computational Fluid Dynamics (CFD) model to capture non-linear flow effects allows being more representative than the linear flow model at all locations across a complex site.
Therefore, more attention is given to these models in the wind energy community and new software packages or CFD extensions with improved calculation cores are available on the market.

But how much do these new models really improve the accuracy of the flow modelling, and therefore the determination of the energy yields to be expected?
A validation of CFD wind field modelling versus field measurement data is essential in order to improve simulation accuracy for long-term AEP estimations.
For this presentation several sites with multiple measurement masts in different countries have been simulated with different CFD model and WAsP, the results have been compared. The CFD calculations have been performed using the O.F.Wind software package based on OpenFoam 12, with Phoenics software, and with the WAsP-CFD model 4.
The comparison of measured and numerically modelled data has been done in terms of mean wind speed and vertical wind profile. The long-term wind speed on each wind turbine position results were also compared to the linear flow model WAsP output.
In our presentation we will shortly introduce the different models and the sites, and then focus on the validation of the models with the measurement masts and on the crosswise comparison. Furthermore, we will show the major pitfalls one can step in during a CFD calculation, such as the importance of the quality of the measurements and their position on the terrain in order to get good model performance.

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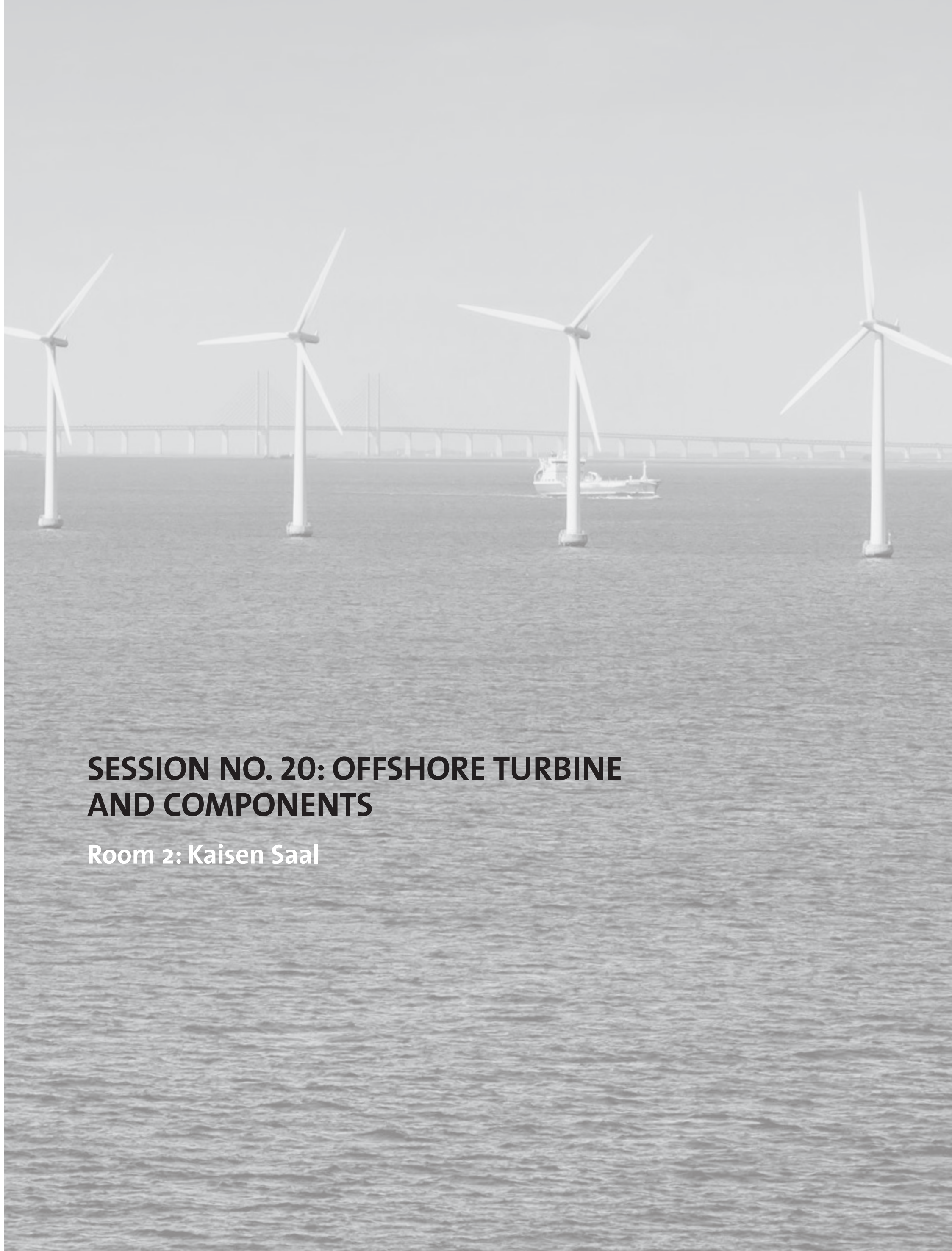

SESSION NO. 20: OFFSHORE TURBINE AND COMPONENTS

Room 2: Kaisen Saal

MEASUREMENT BASED INVESTIGATIONS OF DIRECTIONAL DEPENDENCE OF EXTREME LOAD PARAMETERS FOR OFFSHORE WIND TURBINES

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1. Introduction

The knowledge of extreme environmental conditions and their interaction is very important for a safe and economical design of offshore wind turbines (OWT). For fatigue analyses and operating conditions conditional load parameters (such as wind speed, significant wave height, peak periods etc.) are taken from so called scatter diagrams, cf. [1]. In this way the correlation of different environmental parameters for frequently occurring events is considered. But the correlation and direction dependence of extreme load parameters with return periods of 50 or 100 years is hardly known. If a joint probability distribution does not exist, current regulations advise to superimpose extreme individual events conservatively. There often was a lack of appropriate data to determine joint probability distributions yet. Therefore, existing approaches are based on numerically simulated data [2] and stresses [3] or on data of different measurement locations [4].

2. Approach and results

With the measurement platform FINO 1 synchronously measured series of wind speed, wind direction, wave height, wave period and wave direction are available for a long measurement time.
Investigations of these data show that extreme wind events often do not coincide with extreme sea conditions. For both, extreme wind speed and significant wave height, also direction dependencies could be detected. The highest average and maximum wind speed is expected from the direction west-south-west. The direction of the maximum significant wave height is offset by almost 90 degrees. The maximum significant wave height is expected from north-north-west. A simultaneous occurrence of extreme wind speeds and significant wave heights with a direction offset of 90 degrees can be excluded by the measurement data.
This paper focuses on the directional dependence of extreme load parameters for OWT.
For the analysis of directional extreme events, the measurement data are divided into direction sectors. From the extreme value distributions in each direction the characteristic extreme values with a return period of 50 years are determined. These directional extreme events are compared to each other and to extreme events without directional subdivision. As a result, ratio values of directionally dependent and independent extreme values of relevant load parameters are available. Thus, the influence of direction on the individual load parameters is quantified and the intensity of several rectified load effects can be estimated.

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DETERMINATION OF THE RELIABILITY FOR A MULITMEGAWATT OFFSHORE GEARBOX

Dr. Ing. Dirk Strasser[1], Dr. Ing. Falko Thoma[2], Dipl. Ing. Salih Yüksek[2], M. Sc. Philipp Schmaltz[2]

1. Challenge of the Offshore Market and Requirements for Offshore Gearboxes

The Offshore Market is characterized by increased reliability requirements in order to ensure business certainty and reliable prediction of Costs of Energy.

BOSCH Rexroth (BR) uses the Differential Gearbox Redulus GPV in more than 2000 wind turbines in the power class from 2 to 3 MW. For offshore applications BR uses the Redulus GPC for medium speed drive trains (Fig. 1). The gearbox concept has three planetary gear-stages. The input torque is split on the first two stages and is merged in the third stage. Due to this specific load sharing 3 planets in every stage are sufficient for reaching the load capacity requirements. Thus, there is a statically defined system with predictable loads on bearings and gears, which leads to a very reliable gearbox system.

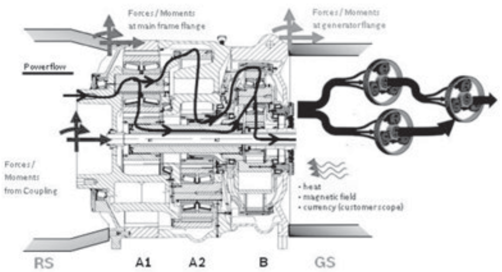

Fig. 1: Redulus GPC Gearbox

The Reliability Engineering on gearboxes offers the possibility to calculate the probability of a gearbox failure in a specific time period. The reliability engineering applying the BR Reliability Approach for this gearbox is explained.

2. Determination of the Reliability

The Reliability Approach of BR is a comprehensive, quantitative evaluation of the gearbox considering all of its relevant components. The failure probability of each component and its failure modes are determined and finally combined in a system reliability assessment based on the method of Bertsche [1]. For this, statistical methods and component tests are used.

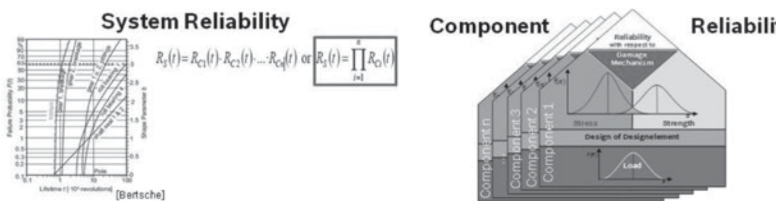

Fig. 2: Component & System Reliability

The basics of the component reliability calculation are introduced and examples are shown. The results are discussed considering the required safety factors acc. IEC 61400-4 [2].
An outlook on future researches is given, e.g. investigations on the scattering of loads or investigations of non predictable failure modes like White Etching Cracks.

3. References

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MODEL TESTING AND NUMERICAL SIMULATION IN FLOATING OFFSHORE WIND TURBINE DESIGN – OVERVIEW AND CONCLUSIONS FROM PRACTICAL APPLICATIONS

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1. Introduction

During preliminary floating platform design for offshore wind turbines, dedicated numerical and experimental methods are required. In the design phase, the applied methods need to be efficient in terms numerical and experimental cost and effort (numerically and experimentally), applicable within optimization frameworks and represent all design-relevant physical effects. Also, they need to accommodate the currently typical industrial design procedure, where the floating platform is designed often without access to detailed data of the wind turbine. An overview is given based on experiences from research and demonstration projects on the required numerical modelling fidelity and experimental tests in different design phases.

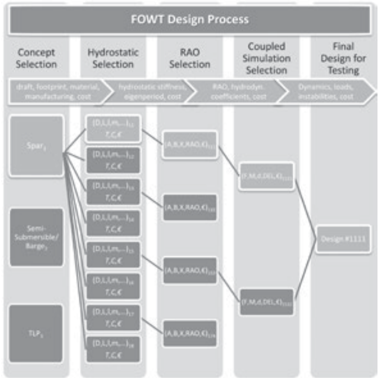

Fig. 1: FOWT design process

2. Methodology

In this paper a numerical pre-design methodology is presented that was applied during the pre-design of a monolithic concrete offshore floating spar platform within the European KIC-AFOSP project [1]. The method has been extended for the current development of a floating foundation for large 10MW+ wind turbines in the European FP-7 project INNWIND.EU [2]. In addition a numerical methodology is presented developed within the scope of the EU FP-7 project FLOATGEN to represent the aerodynamics in the coupled floating wind turbine model with a ring-shape barge without detailed knowledge of the blade properties and wind turbine controller.
Also conclusions from the experimental testing performed within KIC-AFOSP and INNWIND.EU are provided in terms of how the experiments shall be defined and how the results can be well incorporated into the design process.

3. Results

Simplified and efficient sets of equations and methods to derive the relevant hydrostatic and hydrodynamic properties for the FOWT pre-design are presented, as well as a simplified aerodynamic model, which does not require much information of the wind turbine rotor. Extreme values of the platform motion and tower base loads are captured and are conservative using the simplified model approach. Based on the experiences from KIC-AFOSP and INNWIND.EU recommendations are given for a limited but focussed experimental campaign which can provide all most relevant information required during pre-design. The comparisons between experiment and simulations in KIC-AFOSP and INNWIND.EU and the LCOE cost analyses performed for the KIC-AFOSP spar design verify the applicability of the presented pre-design modelling and testing procedures.

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STABILITY ANALYSIS OF FLOATING WIND TURBINE USING 1/64 SCALE MODEL

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1. Introduction

1.1 Research Motivation

Floating wind turbine has a great potential for offshore wind development[1]. However, some studies indicate that the floating platform pitching motion becomes unstable due to the interaction with pitch control[2]. This phenomenon is often referred to as “negative damping”, and it has the possibilities of causing serious damage on turbine structure or any other components.
In order to prevent the negative damping, it is necessary to understand the interaction between pitch control and platform motion. For this objective, we conducted tank test using 1/64 scale floating wind turbine model equipped with pitch control feature. The stability of platform motion under various pitch control gains is experimented, and analysed in terms of pole assignment.

1.2 Method

Fig.1 shows the scale model used for the tank test.

This model is 1/64 scale of MHI’s 7MW wind turbine, MWT/167. The rotor diameter is 2.6[m], and the rated rotor speed is 82.3[rpm]. The platform is an advanced spar type which has plural hulls connected to a column. The model is equipped with pitch control feature. The blade pitch angle is actuated by a servo motor mounted in the nacelle.
In the tank test, platform pitch angle is measured under various pitch control gains during the turbine operates at rated wind speed by pitch control. From the measured platform pitch angle response, linearized models are derived assuming 2nd order system, which is identified by damping coefficient and natural frequency.

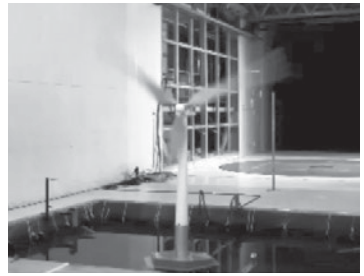
Fig.1: 1/64 scale model

2. Result

2.1 Tank Test Result and Analysis

Fig.2 shows pole assignment of platform pitching motion. Each marker shape represent for different pitch control gains. The coordinate axes are normalized by the natural frequency.

Firstly, it is found that the platform pitch becomes unstable as the pitch control gain gets higher. It is also confirmed that the linearized model well describes the stability characteristic since its poles have the same tendency as test result for the pitch control gain variation.

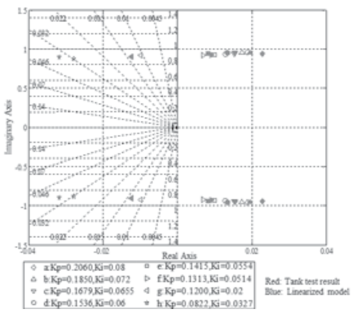

Fig. 2: Pole assignment of pitching motion

3. Reference

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INSPECTING DEFECTIVE ROTOR BLADES BY THERMOGRAPHIC MONITORING FROM GREATER DISTANCES: A REVIEW ON RESULTS OF THE THREE-YEAR PROJECT IKARUS

T. Worzewski[1], R. Krankenhagen[1], M. Doroshtnasir[1]

Established onshore inspection methods for wind turbine rotor blades are not easily applicable to the offshore environment. Therefore, new non-destructive testing (NDT) methods need to be validated, which may detect defects in rotor blades from greater distances – preferably without having to stop an operating turbine. While the comparably fast and inexpensive NDT method of thermography has generally proven to be a suitable tool for investigating subsurface defects in several materials, the applicability to rotor blades in service has not been evaluated yet.
In the framework of the research project "IKARUS"2 it is investigated whether thermographic methods are suitable for inspecting the condition of (offshore) rotor blades from greater distances from an aircraft or ship.

In this presentation, the most important results of three years research are summarized that address issues concerning:

1. Which defects typically occur in rotor blades, and are they in principle detectable with thermography?
2. How do meteorological changes affect an onsite thermographic registration, and which are favorable conditions for monitoring?
3. Can thermography be successfully applied to rotating blades of operating wind turbines, and what are the limitations?

Concerning the first issue, a new statistic on defects in rotor blades is discussed containing over 20,200 repaired damages classified into different aspects such as the type of defect or the relative location of the defect on the blade including its expansion (laterally and with depth). Some typical subsurface defect types are analyzed treating the question as to whether they are detectable with thermographic methods. In that context, the suitability of the sun is tested for acting as a heat source for applying active thermography on GFRP bodies with different thicknesses.
Concerning the second issue, results of a systematic long-term-experiment are summarized where a rotor blade segment of a wind turbine had been exposed to the elements and thereby monitored with passive thermography from a greater distance. It is demonstrated that there are favorable and unfavorable circumstances for imaging thermal contrasts which reflect inner structures and other subsurface features like potential defects. Solar radiation turns out to serve as a very effective heat source, but also other environmental influences such as diurnal temperature variations create temperature contrasts that provide insight on the subsurface conductivity distribution.
Concerning the third issue, it turned out that various challenges arise when the thermographic method is applied onsite to turbine blades in operation. First, an awareness of problems had to be created that arise from monitoring rotating blades. Disturbing influences from the environment easily lead to a misinterpretation of thermographic images. As a consequence, we developed an advanced technique for minimizing disturbing influences, such as thermal signatures caused by reflections and surface inhomogeneities. This technique enables the detection of potential subsurface defects in rotating blades of a wind turbine in operation.

Finally, thermographic data from a helicopter flight over an offshore wind park are presented.

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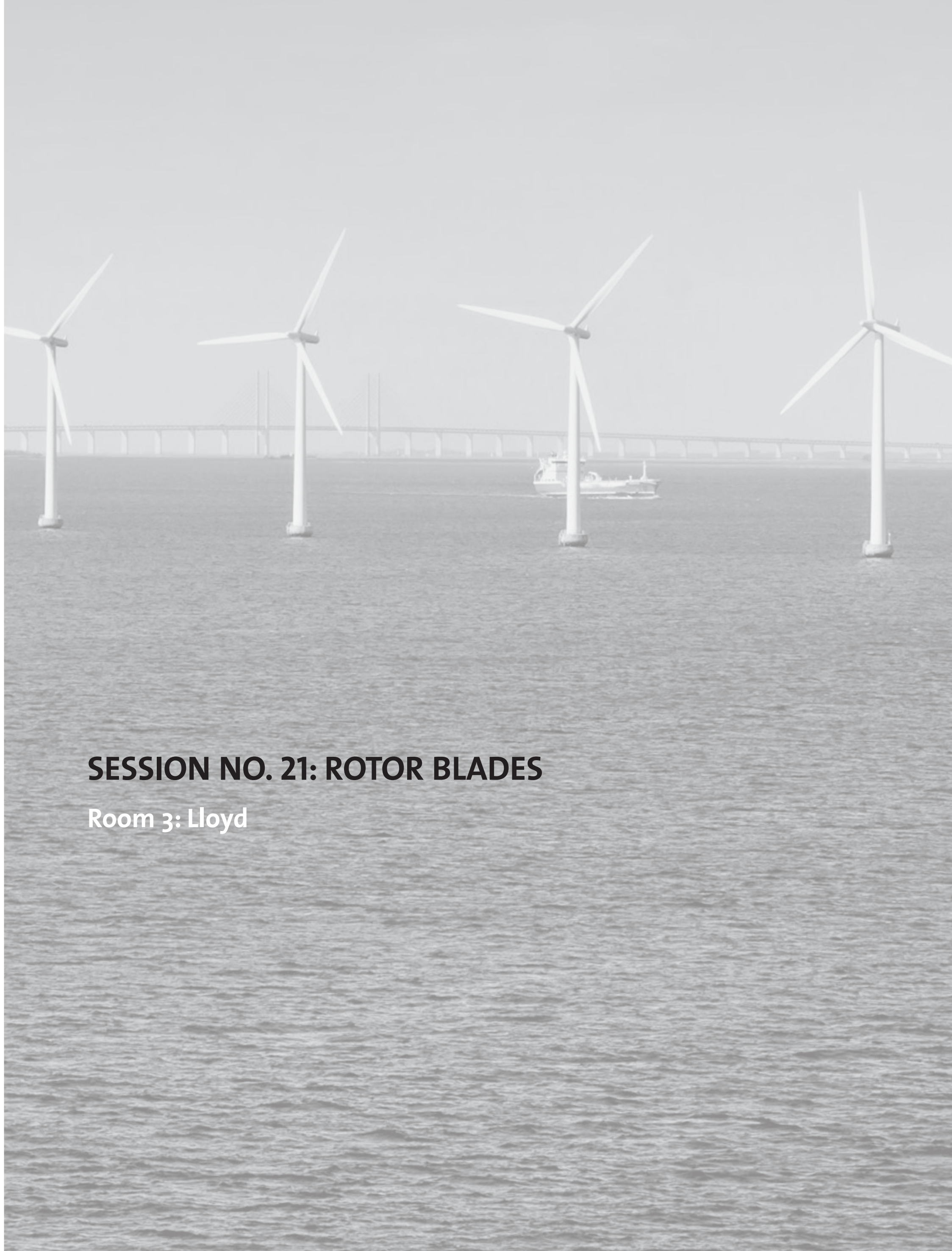
[2] IKARUS stands for: (German) "Infrarot-Kameratechnologie zur berührungslosen Analyse von Rotorblättern unter Hoch-See-Bedingungen"; (Engl.) "Infrared-camera technology for the non-contact Analysis of Rotor blades under Open-Sea-Conditions"



SESSION NO. 21: ROTOR BLADES

Room 3: Lloyd

INVESTIGATING THE AERODYNAMIC IMPLICATIONS OF SLENDER WIND TURBINE BLADE DESIGN

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1. Introduction

A recent design trend for multi MW wind turbines is a strong increase in rotor diameter, while simultaneously the relative chord length is decreased. The paper is analysing the aerodynamic implications of two main design parameters, i.e. design tip speed ratio (TSR) and design lift coefficient, on such modern, slender rotor blades. In addition, the use of thick airfoils and load effects are discussed.

2. Method/Results

Firstly, the influence of an increase of the design TSR on the blade planform and twist as well as power curve, power coefficient and annual energy production is analysed. Some modern three-bladed wind turbines employ a rather high design TSR of up to 10, nonetheless the maximum tip speed is limited due to aeroacoustic considerations. This is possible with variable speed operation only in the lower to medium partial load wind speed range. Consequently the aerodynamic performance is off-design in the upper partial load range.

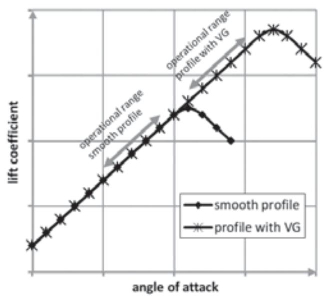

Fig. 1: Lift coefficient with and without VG

The second measure discussed is to increase the design lift coefficient. Since slender blades require thicker airfoils, the prospects of classical high lift profiles are limited. Hence, a novel approach based on patent and data sheet review is presented.
Exemplary patents [2], [3], [4] report a reduction of chord length due to multiple rows of vortex generators (VG).
The lift and drag generated by an airfoil section is proportional to the product of chord length and lift coefficient, respectively drag coefficient. Though application of VG increases the drag coefficient, the chord length reduction counteracts an increase of drag force. The magnitude of lift of the blade is correspondingly maintained, by an increase in lift coefficient. This is obtained by a shift of the design angle of attack to higher values, possible due to stall delay by VG. Fig. 1 shows qualitatively the lift coefficient slope for a smooth profile and a profile with VG.
Furthermore, the variation of aerodynamic loads due to turbulent inflow conditions is elaborated in a qualitative way. On the one hand unwanted stall effects can result in higher dynamic loads, on the other hand a load decrease is possible due to the reduction of lift sensitivity of an airfoil with VG due to the higher overall design lift coefficient.

Comparative assessments of generic wind turbines are conducted in order to illustrate the findings, also in regard to the effects of operational changes in tip speed ratio on performance and loads.
Finally some design examples from commercial wind turbines are presented as far as such data is publically available.

3. References

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BLADE BEARING TESTRIG

Matthias Stammler, Sven Sagner*

1. Introduction

1.1 State of blade bearing development

Blade bearings of wind turbines are subject to unfavorable operating conditions. They have to accommodate high bending moments while standing still or rotating at very low speeds. The surrounding parts, especially the rotor blade, are relatively soft. Possible damage modes are fatigue, edge loading, core crushing, ring fractures, fretting and false brinelling. Currently available calculation methods are not suitable for the conditions found in rotor-blade bearings and do therefore not allow a reliable prediction of their lifetime. Therefore, blade bearing tests are necessary.
This paper is about presenting the requirements for a blade bearing testrig, and appropriate test strategies.

1.2 Motivation

As all major bearing and wind-turbine manufacturers operate various concepts of blade bearing test rigs, Senvion SE has started deriving requirements for blade bearing tests based on risk analysis and own field experiences and to incorporate the enhancements in their own blade bearing test strategy.

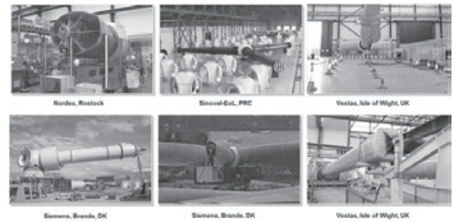
Fig. 1: Competitors Efforts [1]

2. Testrig and test strategy

Based on the outcomes from FMEA and an internal workshop the Senvion product development compiled a detailed blade bearing testrig specification containing the basic concept, part dimensions, metrology requirements and load envelopes.

The Fraunhofer IWES at Bremerhaven was identified as the most suitable partner to bring the testrig requirements into reality.

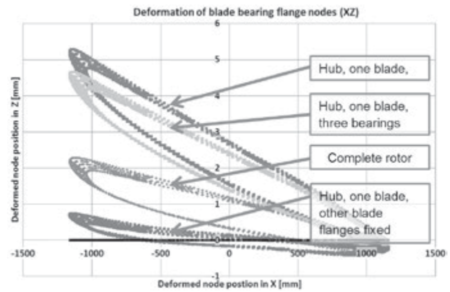

Fig. 2: Hub flange deformation for different configurations

Considering the preliminary requirements, different test rig layouts were simulated and a final solution, incorporating a rotor blade and two additional load levers, was found.

The test strategy is a damage mode driven approach, taking into account the oscillatory movements of blade bearings.

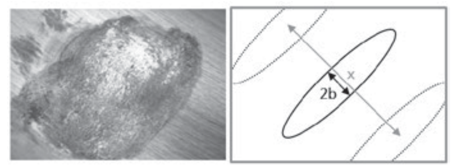

Fig. 3: Fretting damage and oscillatory movement in a blade bearing [2]

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TOLERANCE MANAGEMENT AND ONLINE PROCESS ASSURANCE IN THE PRODUCTION CHAIN OF ROTOR BLADES

Birgit Wieland, Hakan Ucan*, Nico Liebers

1. Introduction

1.1 Production of rotor blades for wind turbines

Nowadays the process steps in manufacturing rotor blades are still mostly manual part [1] while automation systems are not cost-efficient yet. Nevertheless, it will be necessary to improve blade quality to gain competitiveness through better performance and reliability. A cost-efficient method to raise part performance is to implement an online quality control system with a detailed look at tolerance management. Therefore the institute of composite structures and adaptive systems is building up a test facility for online quality monitoring system including a rotor blade mould.

1.2 Tolerance management

For rotor blades not only assembly jigs need to be recognized for tolerance management. The influence of process parameters on composites, especially the process-induced deviations, has a much stronger influence. Such a tolerance chain is shown in Figure 1. To control these process parameters a measurement systems and statistical methods have to be implemented in rotor blade production.

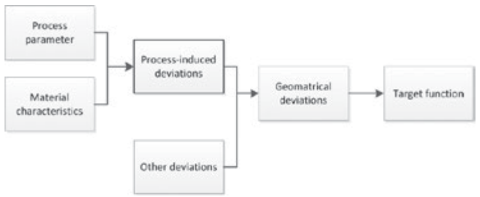

Fig. 1: Tolerance chain for rotor blade

2. Tolerance management and online quality assurance

2.1 The E.V.A.R. – System

The online quality monitoring system E.V.A.R. contains the following benefits:
- Reduction of process time enabled with appropriate curing times
- Less energy usage, e.g. by active use of the exothermal energy of the resin
- Better traceability of parts
- Optimization of the production through continuous analysis of the quality data

Based on the OnQA-System [2] for autoclave processes in aerospace industry a new system, adapted to the needs of wind energy industries has been developed (see Figure 2).

Fig. 2: E.V.A.R. system

The E.V.A.R. system contains temperature and ultrasonic curing monitoring as well as pressure measuring and optical sensors (resin flow, global temperature distribution etc.)
The main benefit of such an online quality measurement system is the opportunity to build up a production controlling and optimizing tool, based on statistical investigations. Here is the link to tolerance management. The process parameter temperature causes thermal stress within parts and fiber composite peculiarities like spring-in effect. Another aspect is the protection of auxiliary and construction materials from overheating through the exothermal reaction of resin.

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FULL SIZE AND COMPONENT TESTS, MATERIAL TESTING, TEST PROCEDURES AND RESULTS, TEST FACILITIES HIGH RESOLUTION X-RAY INSPECTION OF ROTOR BLADES

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1. Testing situation

The production of rotor blades still is a rather manufactory process with low level of automation. This is why rotor blades are not only one of the most extreme stressed structures but also one of the least tested. Quality control in the site of construction is mainly based on visual and percussive testing. Both methods require highly trained personnel and can only detect a narrow set of possible defects. Very few applications of ultrasonic testing underlie to the fact, that this method can hardly penetrate the inhomogeneous material found in full depth.

2. X-ray testing of rotor blades

2.1 XXL-CT

With the world's largest computed tomography system (Fig. 1), EZRT is developing methods to inspect objects that have not yet been accessible by means of X-ray imaging.
2-D X-ray (Fig. 2) allows fast detection of defects in the bonding regions of the blade within a scan time of one or two hours for a whole rotor blade

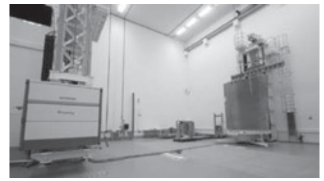

Fig. 1 XXL-CT

2.2 Undulation Quantification

Computed tompgraphy (Fig 3) or laminography offer the possibilities to examine the object in three-dimensional images showing all the inner structures as when cutting the blade in slices. With this power, it is possible not only to automatically detect porosities, inclusions or bonding defects but also to evaluate and quantify undulations in the fibre layers (Fig 4).

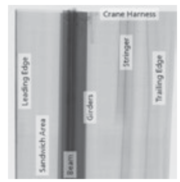

Fig. 2 Radioscopy of a rotor blade

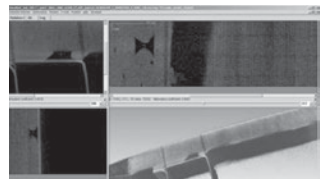

Fig. 3 Computed tomography of a blade.

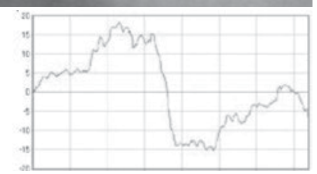

Fig. 4 Tomosynthesis scan of an undulation with quantified orientation.

3. References

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DEWEK 2015

DETECTION OF WAKE IMPINGEMENT BY ROTOR LOADS

Carlo L. Bottasso*†, Stefano Cacciola*, Johannes Schreiber*

1. Introduction

Wind turbines operating in a wind farm may be affected by the wake of neighboring wind turbines. When this happens, the affected machine experiences reduced power output and increased fatigue loading. The implementation of any control strategy at the wind farm level to address this problem, by power curtailment and/or active wake deflection, requires the ability to detect such an interference condition.
This paper describes a methodology to detect wake impingement on a wind turbine by an upstream machine. The detection is based on the use of rotor loads. As rotor load sensors are becoming routinely available on modern wind turbines, for example to enable individual blade pitch control, no additional sensors or equipment is necessary for the implementation of the present method. The use of rotor loads for the detection of wind conditions is a technology that has been proposed and demonstrated in [1-5]. The present work extends the technology to the estimation of the wake state.

2. Methods and results

Wake impingement is detected by a combination of indicators, all based on the wind turbine response. Specifically, blade root loads are used to estimate the local wind speed separately on the left and right parts of the rotor, thereby detecting the possible presence of an area of reduced speed. In addition, the blade load harmonics and phasing are analyzed to detect the signature left on such quantities by the interference with a wake. By combining these two indicators, it is shown that a reliable detection of interference with a wake can be made.
Figure 1 shows some typical results for the local wind speed estimator. The actual and estimated local wind speeds in two lateral quadrants of the rotor are displayed as right bin (in light blue) and left bin (in black). Each subplot refers to a different overlap indicated by the lateral distance between the rotor and the wake center.
The proposed method is capable of estimating with good accuracy the local wind speed, and in particular, it is able to detect variations in wind speed on the two sides of the rotor that are indicative of a wake interference condition. Similar results can be derived for various wind conditions, demonstrating the robustness of the local wind speed estimator.

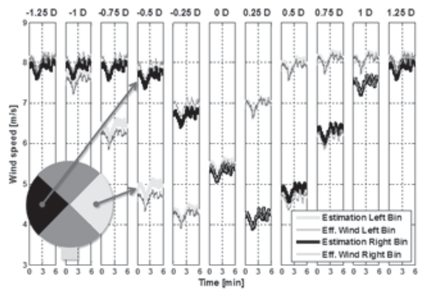

Fig. 1: Estimation of local wind speed on two lateral rotor quadrants

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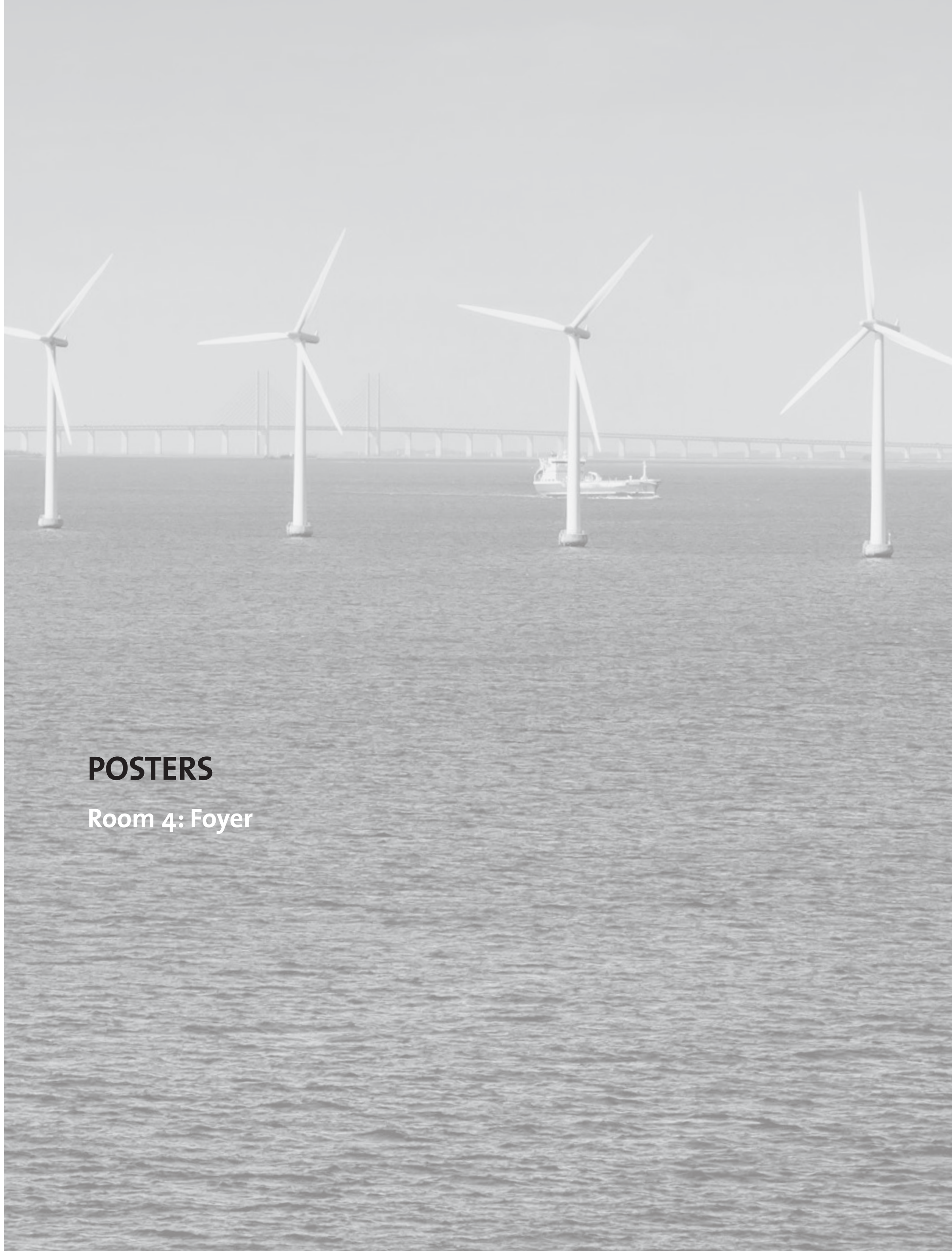

POSTERS

Room 4: Foyer

POSTER 1: VERIFICATION DEWEK 2015

PERFORMANCE VERIFICATION OF WIND TURBINES AND WIND FARMS

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1. Introduction

Even after long years in a mature wind industry owners and operators often don't fully understand the "Operational Behaviour" of their assets. Financiers miss data driven information to set expectations correctly.
It is a critical necessity to measure, interpret and monitor how good wind turbines convert wind energy into electrical power to tell good production from bad and understand the secrets of performance improvements.

2. Availability versus Performance

While wind turbine availability seems to be the measure of well operating wind turbines little attention is given to the actual "operational behaviour" thus the delta of actual versus the possible production.
Based on the analysis of plenty wind farm operational data certain repetitive pattern indicating underperformance are derived from real life examples. Even though at good availability poor performance does reduce the revenue stream. By how much will be shown in exemplary loss revenue calculations.

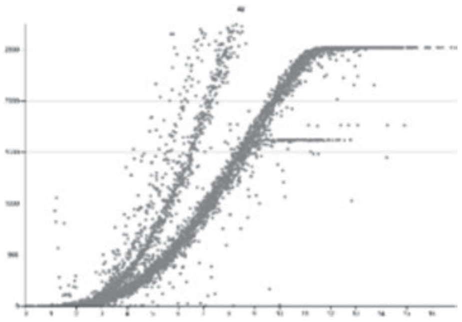

Fig. 1: Performance Issues

2.1. Operation don't lie

Exemplary operational SCADA data of four wind farms is available and was analysed for a turbine individual performance evaluation. Reasons for why wind assets don't earn back their investment are manifold from simple manual failures during system commissioning or maintenance through to incorrect or suboptimal parameterisation of the control system.
Through the application of specially designed analysis processes, it is possible to filter the relevant data. An experience based interpretation of error codes and sequences make obvious the root causes for under performance.
Furthermore the development of adequate O&M strategies lead to an improved performance reducing downtimes and failures enabling better performance, increased production and boosted revenues.

3. Results

The presentation offers insight in real life SCADA data, demonstrates performance issues and subsequent revenue losses and finally highlights corrective actions necessary to better turbine performance but also hints at how to implement control enhancements.

IMPACT OF MARKET-VALUE BASED REMUNERATION ON DESIGN AND OPERATION OF WIND TURBINES

Nicolai Cosack[1, 2], Markus Becker[2]

1. Introduction

The development of wind turbine technology has been very successful over the past years. The levelised cost of electricity (LCOE) has dropped continuously and in many regions wind energy is competitive to electrical energy produced by conventional power plants already.
In Germany, the "Erneuerbare-Energien-Gesetz" (EEG) is the main driver for the technology development. The EEG releases the operators of market risks by guaranteeing that they can sell all the power produced for a defined minimum price. This stimulates private investment into wind power and thereby supports the further development of wind energy technology.
It is foreseeable, that in the long-term this success will eventually lead to a situation, where further support of wind energy technology by legal provisions is no longer required. In the medium-term it is more likely that the focus of the EEG will shift from pure technology development to market integration and that future modifications of the regulations will tend to urge wind turbine operators to marketing and trade the electricity on their own. The presented work therefore investigates if such a shift of the focus can have an impact on wind turbine design and the way in which turbines are operated today.

2. Approach

For this analysis, the wind conditions at regions with a high density of wind turbines in northern and middle parts of Germany are analysed and the energy yield for a typical wind turbine installed in these areas is calculated. The energy yield as well as typical installed capital cost and operational expenses [1, 2] are then used to derive the LCOE for all sites.
In addition, three different scenarios for future remuneration are derived, each reflecting a different stage of market integration of wind energy. The impact of the different scenarios can be included into the calculation of LCOE simply by adjusting the energy yield according to the true market value of the produced energy [3]. Using this approach it is possible to calculate the additional investment that can be spent on certain modifications of the turbine design (e.g. rotor diameter or hub height) and the operation (e.g. shut down at low market-value of the produced energy) so that the LCOE at each market scenario remains at the same level.

3. Results

It can be shown that wind turbine design and operation can be optimised in case the value of the power produced varies, for example due to stronger market integration. In the scenario with the strongest market integration, the additional economic value of increasing the rotor diameter or the hub height is significantly larger than in a scenario with low market integration. Likewise, increasing the service life of a wind turbine becomes more attractive if market integration is strong.

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ESTIMATION METHOD OF THE SUBSIDY FOR WIND PRODUCED ELECTRICITY

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1. Introduction

1.1 Background

Wind turbines are installed to maximize the annual energy production (AEP), regardless of when the power is produced. This is the result of the method of promoting wind energy with a guaranteed feed in tariff (FIT). However, along with the FIT is the necessary subsidy, here defined as the difference between the market price and FIT. Since the price of electricity varies (Fig. 1) as well as the wind speed (Fig. 2) sites will have different required subsidies depending on the daily wind speed. The subsidy amount can be calculated by wind and price conditions and this information used to determine the best turbine siting, which should include minimizing the amount of subsidy a FIT turbine requires as this is also a cost that must be paid by the consumer.

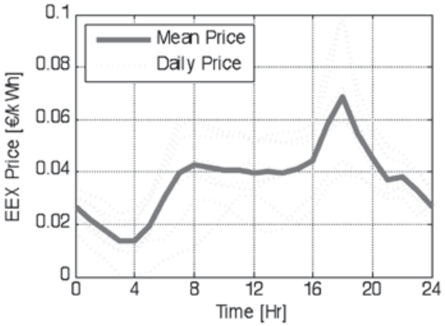

Fig. 1 Electricity Market Price (EEX)

1.2 Methodology

A standard site assessment for a wind turbine is concerned with determining the AEP. With the FIT, this allows for the revenue to be determined. By measuring the wind conditions for an extended period, calculating the wind speed distribution and multiplying the distribution by the power curve of the turbine, the AEP can be calculated.
By modifying this method to calculate the hourly wind speed distribution, an hourly capacity factor and energy production can be estimated. This data can be used to estimate the production market value, given an estimated hourly price (Fig. 2). The FIT minus the market value is the required subsidy for the production.

2. Results

Data provided by the NREL were used to determine the hourly production for a multi-year measurement campaign [1]. The hourly capacity factor was able to calculate the market value of the production (using an assumed daily price curve for the entire year) to an accuracy of greater than 95%. The market value can then be subtracted from the FIT revenue to calculate the necessary subsidy. The result is a method to estimate the €/kWh subsidy for wind energy and the overall cost to consumers.

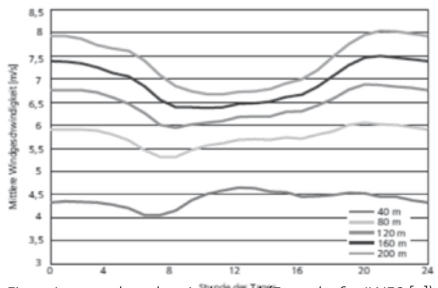

Fig. 2 Average hourly wind speed (Fraunhofer IWES [2])

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THE WIND FARM WHISPERERS: DATA ACQUISITION AND ANALYSIS FOR OFFSHORE WIND FARM OPTIMIZATION

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1. Introduction

The delivery of offshore wind projects in European waters requires a complete, accurate and detailed understanding of the wind conditions prevailing at the offshore wind farm sites, and a thorough understanding of the response of wind power assets to these conditions. If these are known: the observed wind resource can be reconciled with revenues post-construction; observed production can be reconciled with predictions made pre-construction; and wind farms can be optimized both during design and operation to maximize output and minimise operational expenditure. A single unified approach to the assessment of wind power assets' total lifecycle compatibility is required in order to achieve meaningful and lasting asset optimisation. Currently this approach is prevented by discrepancies between project data requirements pre- and post-construction. These discrepancies are an artefact of limitations in measurement opportunity that are now being overcome, and procedures for project development and operation should be revised to reflect this.

2. Implementation

Data acquisition has typically fulfilled pre-construction priorities. These priorities have arisen from the need to secure finance and support investment decisions. The data requirements this entails have been limited hitherto by restricted opportunities to make measurements and limitations in the capabilities of the available instrumentation. Some significant issues have come to light only after construction when they have been manifested as poorer than expected wind turbine availability or power performance. New tools and techniques, such as lidar, are available that allow the adoption of a more unified approach to data acquisition and analysis suitable for full lifecycle project optimization. This presentation will review the new frontiers in the ever-changing technical context in which offshore wind projects are delivered, as new measurement opportunities and the analyses that accompany the data acquired as a result bring our assessments closer to the accurate representation of the reality of offshore wind. Data requirements for pre-construction wind assessments have typically reflected limitations in measurement opportunity; while post-construction a deeper understanding of the wind conditions and the response of wind power assets is necessary for their optimisation. New technology is overcoming these limitations and it is now possible to observe adverse conditions pre-construction rather than wait for their manifestation in sub-optimal performance post-construction.

3. Conclusion

Wind asset optimisation is supported by the adoption of a single unified set of data requirements throughout the project lifecycle, based on the representation or reality rather than the limitations of our instruments. This allows us to:

- Describe the data requirements that arise during different phases in offshore wind project delivery and how these relate to real project objectives and measurement opportunities
- Differentiate between risks associated with wind conditions offshore, and risks that are artefacts of our limited but improving ability to assess those conditions
- Make progress towards a unified and well supported view of our assets' compatibility with real wind conditions over the full project lifecycle

OPERATIONAL ASSESSMENT OF POWER PRODUCTION

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Monitoring wind farm performance is very important in terms of optimization. Besides condition-monitoring, the real production has to be monitored as well. While the meteorological site assessment gives indication of the expectable average long term production, there is no indication, if a wind farm does really perform well in the current wind situation. Operational assessment of power production will close this gap of information. The approach uses metering or SCADA data and a production simulation, based on wind speeds from downscaled reanalysis based time series. The result allows a comparison with the observed power production in the analysed period of e.g. one week or one month. It gives insight into the long term classification and operation performance of the specific period with great value for controlling purposes.
As long as reanalysis data sets are updated only on a delayed monthly basis (2-6 weeks delay), a gap filling is used. This is realised by using actual GFS operational analysis data, which correlates well with the reanalysis data on an hourly basis (corr > 0.95). The wind speed in hub height is downscaled by a parametric methodology [1] and transformed into energy production using the wind farms individual power curve, and also taking into account the wake losses of a Jensen-based wake model.

A sophisticated calibration is made using Machine Learning Techniques [2] on historical production data and the historical wind time series, derived from reanalysis information. It results in a non-linear transfer function from reanalysis based production to measured production which is applied to the actual period.
Internally, an hourly time series of the production is generated for the desired period, which is varied with all the assumptions, made for the site assessment. Therefore, technical availability leads to production reduction as well as the assumptions made about wake losses or availabilities due to bats, shadow, noise or icing. An Ensemble of all the availabilities is calculated for the period's production and statistics are derived. The resulting report shows if the period's production follows the assumptions made in the site assessment, without losing the focus on the periods long term wind situation. Under or over performance of the wind farm can be monitored and further optimisation can be applied.

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FWT 3000 – EXPERIENCES WITH THE PROTOTYPE

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The FWT 3000 is a new generation of high-yield wind turbines in the 3 MW class. This model was developed specifically for the growing market of medium and low wind sites. It stands out thanks to its low weight, an especially low-maintenance design and significantly lower running costs.

Advantages of the FWT 3000 at a glance:
- Compact drive train concept: hybrid drive, compact design, load reduction and defined loads for the gearbox with a grip and torque bearing connected to the motor mount
- Smart pitch system: robust, low-maintenance design with load reduction based on a single-blade pitch
- Safety system: reduced signs of wear and extended service life thanks to differentiated actuator release based on events

The striking design with side scoops and coolers means that the FWT 3000 is not only visually distinctive, but also highly functional. The natural flow of air around the body is used for optimal cooling.

The hybrid drive combines a two-stage gearbox and a medium-speed synchronous generator, allowing a compact nacelle for the FWT 3000 – much easier to achieve with a weight of almost 105 tons as compared to other 3 MW models. The 120-metre rotor and hub heights of up to 140 metres deliver a good yield of energy even in low wind conditions and at sites with complex topography. The new technology ensures even greater efficiency and safety: three patents alike indicate a high level of innovation.

Thanks to its full-scale inverter, the FWT 3000 facilitates straightforward grid integration with a broad range of grid codes and is also prepared for future network protection regulations.

The FWT 3000, developed by the engineering office W2E in Rostock and built by FWT in Waigandshain, convinces with technology and capability. In addition, this concept safes construction length and weight of the nacelle, this reduces costs and simplifies logistics.

The prototype FWT 3000 was built in September 2013 nearby Rostock and works sufficiently with high revenues, according to statements of the operator. The plant with a hub height of 100 m has a 120 m rotor. Planning is underway for the construction of an FWT 3000 at an inland-location for a 140 m hybrid tower.

With this, FWT stays on the road of success: By now the company employs around 80 experienced staff members in the sectors Service, Production and Trade.

THE DEVELOPMENT OF PRESSURE RIGIDISED BLADES – THE CHALLENGES

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1. Introduction

1.1 Pressure rigidised airfoils

The design and operation of pressure rigidised inflatable wings have been used in full-scale aircraft [1] and UAVs [2] applications. Typically, an inflatable wing construction (Fig. 1) consists of either singular or modular volumes which consist of a stiffening member and a gas retaining member. Some advanced composite materials may satisfy both the latter requirements. Structurally, these designs are either permanently or initially flexible, depending on application. A permanently flexible design requires a retaining pressure which is governed by the hermetic properties of the material and the inflation volume. Initially flexible designs are only inflated once thereafter the structural materials permanently rigidised via chemical or UV curing processes. The research presented aims to extend the application range of inflatable airfoils to rotatory applications, specifically, wind turbine blade design.

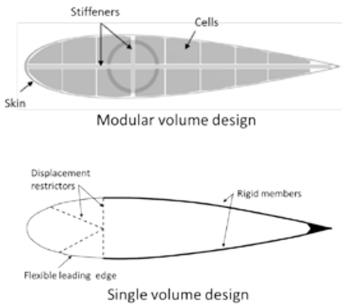

Fig. 1 Pressure rigidised inflatable airfoils

Criteria	Options			
Inflation	Permanently	Semi-permanent		Non-permanent
Inflation volume	Less than half blade volume	Half blade volume		Full blade volume
Inflation actuation	Mechanical		Chemical	
Rigidisation member location	Internal (torsion box)	External (skin)		Both
Pressure rigidisation scheme	Single volume	Multiple volumes		Only at surface (nastic)
Rigidisation pressure	1 atm ≤ P ≤ 10 atm			
Temperature	-20 °C to 50 °C			
Materials	Fiber-reinforced elastomers [3]	Woven/knitted textiles [4,5]	Thin composite shells [6,7]	Polymeric membranes [8]
Aerodynamic control	Active (e.g. morphing, flaps)		Passive (blade twisting)	
Morphing	Full blade	Blade sections		Trailing edge

Fig. 2: The possible design considerations

1.2 Blade design considerations

A range of conceptual designs are possible as evident from Fig. 2.

2. Challenges

2.1 Aerodynamics

Inflatables produce shapes of various curvatures which in turn will affect the aerodynamic performance thereof. These are explored using CFD models.

2.2 Structural design

Conventional blade loading and failure mechanisms are known. The correct modelling of the materials for the various operational conditions is complex. The design of the transitional structure between the aerodynamic structure and blade root is also complex.

2.3 Control design

The active control using profile morphing may be applied to the whole blade or blade section.

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MULTI-MEGAWATT WIND TURBINE DRIVE TRAIN WITH MULTIPLE HIGH-SPEED GENERATORS

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1. Motivation

High-speed electrical machines offer an increase of power density and cost reduction. Since there are no applications of this technology in wind turbines generators (WTG) so far, an alternative 6 MW WTG drive train with six high-speed (n = 5000 min-1) generators (Fig. 1) will be developed to analyze the potential of high-speed electrical machines in WTG. The proposed drive train configuration combines the advantages of WTG concepts with multiple generators with the high-speed technology of electrical machines.

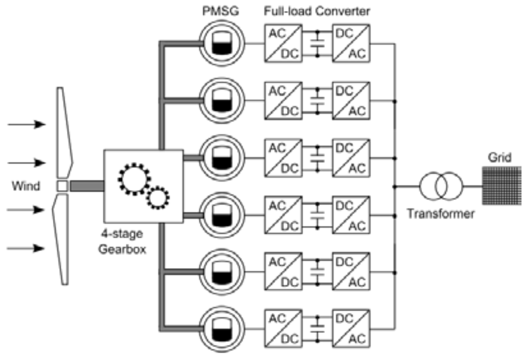

Fig. 1: Drive train configuration

2. Drive Train Configuration

The gearbox used in the proposed drive train configuration needs a higher ratio compared to conventional WTGs. This leads to additional gear stages with new challenges for gears, bearings and the lubrication system. Furthermore the power split for multiple generators leads to an advanced complexity as well as to an increase in weight and material compared to conventional gearbox concepts.
On the generator side the targeted higher speed results in an increased power density, which brings a considerable weight- and size reduction of the generators. This reduces the amount of magnetic active material and leads to a decrease of investment costs.
The design with multiple equal generators enables the utilization of more identical and at the same time smaller and lighter parts, to achieve a better economic efficiency in production and improvements in maintenance. A certain redundancy of the system is given as well, since energy will always be produced, even in case of a malfunction of one generator.

3. Operating Strategy

With a multiple generator drive train concept the operating strategy of conventional WTGs (speed control at partial load and power control under full load) has to be adapted. Here, a special focus is put on the partial load range, since at both, high and low wind sites, about 70 % of the time the average wind speed comes up to the range of partial load operation.
To operate the WTG during partial load in order to permit an optimal efficiency, the rotor speed is adjusted so that an optimum tip speed ratio opt is reached. The use of multiple generator concepts offer the possibility to shut down generators at partial load individually. Thus, the remaining machines will operate in higher power ranges and so at higher efficiencies. Moreover, it is possible to use at different times different generators, so that each generator has a shorter working time than the WTG is in operation.

In this paper first investigated concepts for the gearbox and generator configuration for the WTG will be presented. The main focus is on the operating strategy which will be simulated for different operating conditions to discuss the potential of load and efficiency optimization of this alternative drive train design.

THE NEXT GENERATION OF FLEXIBLE CRANE SYSTEMS IN WIND TURBINE NACELLES

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1. Introduction

1.1 Introduction

As wind turbines have developed in size, there is a growing need for an easy and safe transport of spare parts and materials inside the nacelle, due to longer transport ways. Besides reducing the production and installation costs, the third also very important factor for the industry is the cost of operation and maintenance.
If time of maintenance could be reduced and made more efficient, with less risk of accidents, the industry would save cost.
Terex has, with its brand Demag, in an innovative way developed a new solution for the wind industry, based on reliable technology.

1.2 Challenges

How do you transport parts inside the large nacelles of today and tomorrow, when parts must be transported longer ways with the risk of accidents?
Till now, a simple jib crane mounted in the back end of the nacelle was sufficient, but the reach of such a crane is limited in the new turbine sizes over 5 MW.
Secondly when every minute is cost, also waiting time for lifting and lowering of parts with chain hoist, becomes crucial as towers now can be up to 180 meters high.
Furthermore, as turbines are installed offshore, the need for a crane system with no hydraulics is important to keep maintenance cost as low as possible.

2. Solution

2.1 Reduce hoisting time with up to 50%

With the combination of proven technology, it is now possible to radically reduce the maintenance time for wind turbines and offer a safe working environment at the same time.
The new rope winch DS10 offers a lifting speed of up to 48 m/min, which reduces the waiting time with up to 50% compared to typical chain hoist solutions.
For the internal transport with industrial well-known KBK Modular Crane System, tailored to meet the requirements for linear smooth overhead handling, is offered.
An example is shown above in Fig.2.

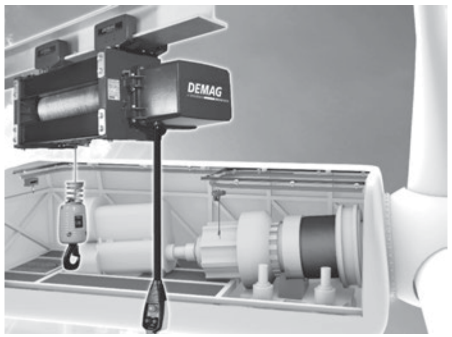

Fig. 2: Example of turbine layout

2.2 Conclusions

Advantages for the users:
- Time saving = cost saving
- Safe working environment
- Material savings – rope instead of chain (weight and size)
- Flexibility of system inside nacelle
- No manual transport of components
- Easy moving of parts
- Less space consuming than a hydraulic crane
- Low maintenance cost of crane system

PASSIVE LOAD REDUCTION IN WIND TURBINE BLADES WITH AN ADAPTIVE CAMBER AIRFOIL

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1. Introduction

1.1 Load reduction in wind turbine blades

Reducing fluctuating loads in wind turbine blades, presents a way to increase wind turbine durability and lifetime. First, due to a reduced fatigue stress, the blades can be built lighter, reducing the scaling exponent of the rotor costs. Second, fluctuating loads on other wind turbine components are alleviated, extending their lifetime.

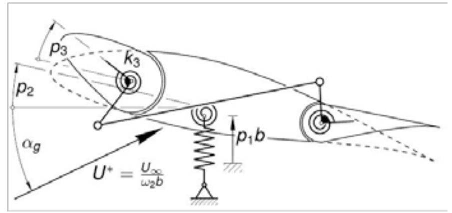

Fig. 1: Adaptive camber airfoil.

1.2 Adaptive camber airfoil

The adaptive camber airfoil, developed by Lambie [1], is a passive mechanism integrated in the outer parts of a wind turbine blade. It consists of a leading flap kinematically coupled to a trailing flap (cf. Fig. 1). The pressure distribution on the leading flap is proportional to the current angle of attack. Consequently, the aerodynamic moment on the leading flap is used to actuate the trailing flap via the coupling mechanism. This renders the lift slope and the lift at the design point tunable. If, for instance, the lift slope is small, the airfoil is less sensitive to changes in the inflow conditions and load reduction is achieved.

2. Load reduction

2.1 Definition

The standard deviation of the heaving degree of freedom *p1*, can be interpreted as a measure for the fluctuating loads. The standard deviation σ is, therefore, used to define the load reduction as

$$LR_{p_1} = 1 - \frac{\sigma(p_{1,adaptive})}{\sigma(p_{1,rigid})}$$

where the subscript adaptive denotes the signal of the adaptive camber airfoil and the subscript rigid denotes the signal of the rigid reference airfoil.

2.2 Results

The achievable load reduction is displayed in Fig. 2, as a function of the flaps to pitching degree of freedom eigenfrequency ratio K_1. Here, the system, displayed in Fig. 1, was excited with a signal once having a rotationally sampled power spectral density (solid line) and once having a von Karman spectrum (dashed line). The curves are obtained for different wind velocities. Fig. 2 indicates that load reductions up to 80% are possible.

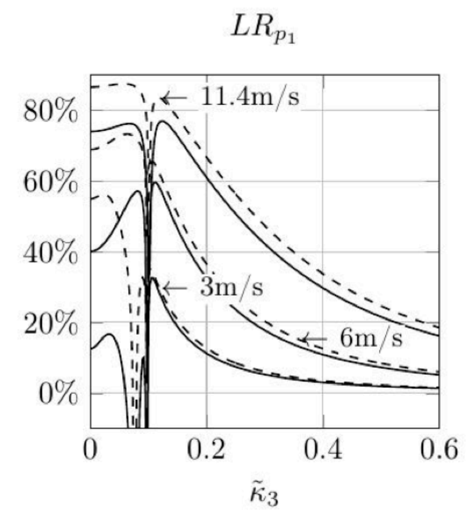

Fig. 2: Load reduction of the heaving degree of freedom.

3. References

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BEARING UPGRADES IMPROVE FIELD PERFORMANCE AND LEAD TO FUTURE DESIGN PRACTICES

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1. Subject Area

2. Last technical developments of wind turbines and components

2. Abstract

Wind turbine main shaft and gearbox bearings may experience a variety of life-shortening situations. Three of the most significant areas of concern are associated with Spherical Roller Bearings (SRB) on main shaft 3-point mount turbine design, on planetary wheel bearings, and on High Speed Shaft (HSS) gearbox bearings.
The Timken Company has developed specific solutions, which have been applied as replacement parts, and which is experiencing positive feedback from wind farm owners and operators.

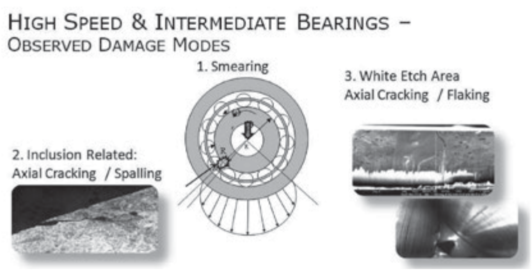
Main Shaft SRB

Based on extensive investigation, the primary damage mode observed is micropitting, which eventually leads to macro spalling. The physical mechanisms which are leading to this failure mode are now well known. Timken is offering a Wear Resistant Bearing solution which is a combination of enhancements articulated around a special "DLC" coating.
This solution is actually having a great success in the aftermarket in United States for main shaft repair.

TECHNOLOGY	DESCRIPTION	BENEFITS
Roller Finishing	Low Roughness, Isotropic Finish	Reduced Asperity Contact & Stress
Roller Coating	WC/aC:H Coating 1 µm thick	Increased Wear Resistance, Increased Fatigue Life, Increased Debris Resistance.
Internal Geometry	Roller/IR Conformity	Decreases Roller Stress, Reduces Potential Roller Skew Creates Favorable Traction
Split Cage	Two-Piece Machined Brass Cage	Lowers Possible Operating Forces

Gearbox

- Planet Wheels are prone to debris damage and heavy loading. On output shafts, white edge cracks (WEC) damages are commonly observed. For both cases, Timken Case Carburized bearing material and process helps reducing these damage modes and is a common repair solution by wind farm owners and operators, particularly in North America.
- Additionally, in low speed positions, like planet wheels, the Timken DLC coating will reduce micropitting risk.



OPTIMIZED MATERIALS FOR WIND TURBINES

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1. Introduction

1.1 Background

As a result of the increasing size of modern wind turbines, the effects of interference in radar function continue to be a challenge. One of the many resulting effects of interference is the increase of their radar cross section (RCS). Especially the rotating blades of a wind turbine cannot be filtered out by radar units, thus causing the most interference in radar detection. It is therefore, highly problematic to upgrade or build wind turbines near radar stations. [1]

1.2 Research Objective

The research objective is to investigate potential radar absorbing materials (RAM) for integration in a glass fibre reinforced composite (GFRP) of a turbine blade in order to minimise the radar reflection of wind turbine blades. The actual focus of investigation is at a frequency range of 2.7 – 3.2 GHz which complies with the range of Air Traffic Control (ATC) Radar according to ECA-Table [2].

1.3 Requirements & Restrictions

Regarding the technical and economic aspects of a radar absorbing blade, the authors identified some basic requirements. In order to fit the economic requirement the involved materials as well as the integration method should be highly cost-effective. From a technical point of view the absorber system needs to be lightweight and must not have an influence on the mechanical properties of the (GFRP). Finally, the limited wall-thickness of wind turbine blades restricts the maximum thickness of the absorber system.

2. Research Approach

2.1 Materials

The investigated RAMs are carbon-based and include several kinds of carbon black (CB) and carbon short fibres. According to the listed requirements above they have the advantage of low costs and low weight.

2.2 Method of Integration

The chosen method for integration consists of absorbing layers (AL) which are located between the glass fibre mats. The intermediate layers consist of a carrier material coated by RAM and possess a defined complex, permittivity with relative high loss factor. The final result of the investigation is a GFRP with several modified layers which are chosen by permittivity and placed in the optimal slots to maximise reflection loss.

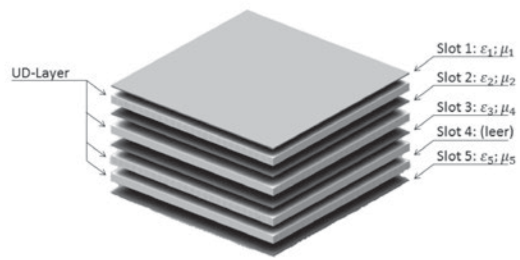

Fig.1: Exploded View: GFE with 5 Slots

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EXPERIMENTAL FATIGUE ASSESSMENT OF HIGH STRENGTH BOLTS WITH LARGE DIAMETERS IN CONSIDERATION OF BOUNDARY LAYER EFFECTS

P. Schaumann[1], R. Eichstädt[1], M. Oechsner[2], F. Simonsen[2]

1. Motivation

High strength bolt sets with large diameters between M36 and M72 are used in bolted ring flange connections in steel support structures for wind turbines. Protection against corrosion of the bolts is commonly achieved by hot dip galvanizing. It has been shown that the zinc coating has an influence on the fatigue strength of bolts [1]. However, due to high mean loads the experimental prediction of the fatigue strength and the quantification of the boundary layer effect is very demanding for bolts with large diameters.

2. Investigations

Within a joint research project (IGF-Vorh. Nr. 486 ZN) the fatigue behaviour of large size, high strength bolts in consideration of boundary layer effects is systematically investigated. The experimental investigations comprise extensive fatigue tests under axial loading of bolts M36 with different boundary layer configurations. In order to achieve a realistic stress level, the tests are performed under high mean stress of $0.7 \cdot R_{p0.2\%}$, which corresponds to the nominal preload of the bolts of 515 kN according to EC 3. The experiments are conducted in a high frequency pulsator located in the recently opened Test Centre For Support Structures in Hannover (TTH), cf. Fig. 1.

Furthermore, the test program on high strength bolts includes large scale tests of bolt size M64 as well as fatigue tests under variable amplitudes of bolt size M36.

In addition to the direct quantification of the boundary layer effect the test results will be used to verify the applicability of an analytical assessment method based on the notch strain approach. The analytical fatigue life assessment method, currently under development, focuses on the inclusion of boundary layer effects and on the predictability of fatigue life under variable amplitudes.

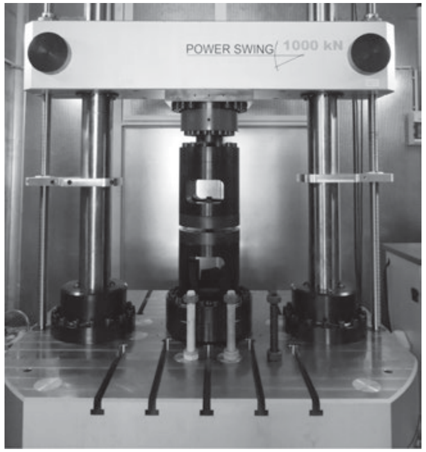

Fig. 1: Test set-up with bolts M36 at the TTH

3. Results

This paper focuses on the fatigue tests of large size bolts under axial loading with high mean stress level. Results will be presented for three complete S-N curves of high strength bolt sets of size M36 with the boundary layer configurations black bolt, normal temperature hot dip galvanizing and high temperature hot dip galvanizing. Thus, the effect of the zinc coating in the high cycle fatigue regime as well as on the fatigue limit strength of the bolts can be quantified.

Additionally, an outlook on the fatigue tests on bolts size M64 and on the experimental investigations with variable amplitudes on bolts M36 will be given.

4. References

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EXPERIMENTAL AND NUMERICAL GENERATION OF TURBULENT INFLOW CONDITIONS FOR WIND TURBINE AIRFOILS

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1. Motivation

Wind turbines operate in highly turbulent environment. Aerodynamic load fluctuations cause fatigue loads which reduce the lifetime and limit the upscaling of turbines. A passive load alleviation concept with kinematically coupled leading and trailing edge flaps has been developed at TU Darmstadt, [1], to reduce these fluctuating loads. The concept has already been tested and validated under steady inflow conditions. In a next step, an airfoil equipped with this concept will be examined experimentally and numerically under unsteady inflow conditions.

2. Approach

The wake of a bluff body is used to generate periodic angle of attack (AoA) variations. A slotted cylinder was chosen because of its distinct vortex shedding. A parameter study was carried out in order to generate appropriate inflow conditions for the load alleviation mechanism, which could also be reproduced numerically. Different velocities, slit inclinations and cylinder positions were tested.

Fig. 1: Experimental setup

3. Experimental and numerical setup

The experiments have been conducted at the low speed wind tunnel of TU Darmstadt. The cylinder slit inclination and its spanwise position are variable. Hot wire measurements have been carried out in the far wake of the cylinder.

The CFD simulations have been performed with FLOWer, a block structured code developed by the German Aerospace Center (DLR), which solves the compressible Navier-Stokes-Equations. Parametrical numerical studies on the impact of the cylinder position relative to the walls on the wake amplitude and periodicity were performed.

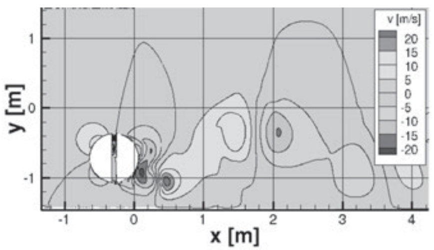

Fig. 2: Predicted variation of the vertical velocity v [m/s]

4. Results and Comparison

An orientation perpendicular to the inflow of the slit led to the most two dimensional flow field. For this configuration experiment and simulation show a good agreement in terms of regularity, frequency and amplitude of the AoA variations. AoA amplitudes at the future airfoil position can be reduced for closer wall proximity of the cylinder.

The paper will include a detailed description of the experimental and numerical setup, the characterisation of the inflow conditions and a comparison between measurement and simulation.

5. References

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WIND TUNNEL APPLICATIONS FOR WIND ENERGY IN BRAZIL

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1. Introduction

This article aims to briefly describe the specification of a wind tunnel for wind energy applications and its main aspects. It also contains a literature review of experiments to be performed in the wind tunnel that are of interest of the Brazilian wind energy sector. This wind tunnel will be also used to perform accredited calibrations of anemometers.
Wind energy in Brazil has been passing through an important moment of development taking into account the installation of several wind farms throughout the country. Since 2009, energy auctions have been occurring, t resulting in 4.5 GW of installed wind power capacity, coming from 181 wind farms, concentrated in Northeast, South and Southeast regions of Brazil, until now [1].
Concerning wind energy applications, the wind tunnel can be helpful for the study of small and large wind power applications like aerodynamic project of wind turbine blades, interference between wind turbines, wind turbine wakes characteristics and others.

2. Wind tunnel specification

The main aspects of the wind tunnel considered in the specification are: turbulence intensity, flow quality, type of circuit of the wind tunnel (open or closed), type of test section (open or closed), maximum velocity in the test section, size of the test section and others. Some of these aspects are considered in order to guarantee the required quality of the flow for the experiments and for the anemometers calibrations.

3. Wind energy studies in the wind tunnel

3.1 Study of improvement in small wind turbine blades

The market for small wind energy in Brazil is still incipient, unlike the Chinese and North American markets. One of the barriers to the expansion of this market is the lack of incentives to domestic manufacturers, not reaching the scale effect and, by extension, attractive prices. The support to domestic manufacturers, in the form of research and testing in the wind tunnel, will support the development and improvement of the national wind turbine, considering the local conditions, making them more efficient, quieter and more resistant to aerodynamic efforts, as well as to contribute to the consolidation of a national industry.

Testing new airfoil profiles
Recently, in [2] and [3], low Reynolds number airfoils were designed for small horizontal axis wind turbines to achieve better startup and low wind speed performances.

Tests of wind turbine rotors (reduced scale model or actual size rotors)
The results of wind tunnel tests performed on a full scale horizontal axis small wind turbine with a rotor diameter of 1.2 m are presented in [4].

3.2 Studies with reduced scale models of large turbines

In [5], a study that aims to contribute to the understanding of the turbulence structure of the flow inside and above a large wind farm is presented. Results are presented from wind-tunnel experiments carried out using a 10 by 3 array of aligned model wind turbines under two different spatial configurations.
For all cited applications and some others, several required conditions of the experiments such as test velocities, turbulence intensities, instrumentation and measurements to be performed, among others, will be presented.

4. References

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AUTOMATED AND QUALITY ASSURED PRODUCTION CHAIN FOR ROTOR BLADES

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1. Introduction

In 2013, the DLRs' Center for Lightweight Production based in Stade started a research approach, with the main goal to develop an automated and quality assured production chain for rotor blades. In this case projects are currently processed. The research works that are discussed in this paper concentrate on three important steps in the production chain of rotor blades: Direct-Fiber-Placement-Process (see chapter 2.1), development of a sensor integrated rotor blade tooling (see chapter 2.2) and of a smart process monitoring system (see chapter 2.3).

2. Overview DLR Projects

2.1 MoDiFaR[1] (EU)

In the EU (EFRE) funded project MoDifAR the DLR is obtaining a Direct-Fiber-Placement unit equipped with a new fiber placement technology. The goal is to enhance layup rates and layup quality of large lightly curved preforms like rotor blade shells with full flexibility on layup angles while reducing tool occupation time and fiber scrap. Processing raw fiber material directly from the coil, the material and manufacturing cost can be signi-ficantly reduced compared to the state of the art fabric processing.

In the course of its further development this unit will be modified and optimized for the manufacturing of tailored glass fiber preforms and the usage on a mobile robotic platform, making it even more flexible and interesting for a Multi-Head-Coordinated-Layup approach (see Figure 1)

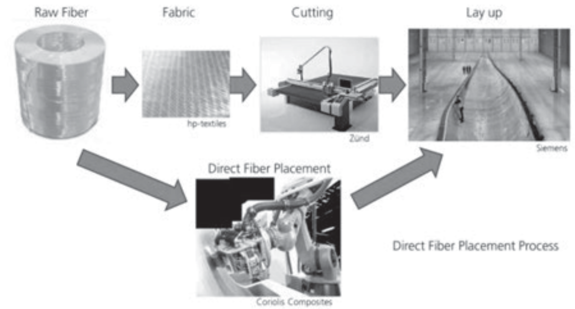

Fig. 1: Direct-Fiber-Placement-Process

2.2 SmartBlade (BMWi[2])

The development and construction of a smart rotor blade tool is one of the main goals in the project SmartBlade. The integrated sensor systems in the tooling are for supervision and control of the injection and curing process. The rotor blade tool will be equipped with temperature, pressure, and ultrasonic curing sensors to get an insight into the curing process and to have the opportunity for online control and manipulation of the curing process, making this rotor blade tool a veritable smart tool.

2.3 DPW-Design (BMUB[3])

The central point of view in the DPW Design project (Develop Pro Wind Design) is the development of smart monitoring and control system with the objective to perform the gathering, processing and exchange of all relevant information within the system during the curing process in the sensor integrated rotor blade tool (see chapter 2.2). This process information – from the integrated sensor systems, but also from different optical sensors – will be used in return to optimize the polymer reaction to increase the process reliability, to ensure the required part quality and to reduce cure cycle time. The evaluation of a new measurement system and their software are part of this development.

[1] Mobile Direct Fiber Placement for Automated Rotor Blade Manufacturing
[2] Federal Ministry for Economic Affairs and Energy
[3] Federal Ministry for the Environment, Nature Conser-vation and Nuclear Safety

POSTER 4: SIMULATION I (WIND TURBINE) DEWEK 2015

INDUSTRY 4.0 IN THE WIND POWER INDUSTRY ON THE EXAMPLE OF INTELLIGENT HYDRAULIC BOLTING TO MEET THE VDI/VDE 2862 PART 2

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Industry 4.0 stands for the exchange of data along the entire value chain. The collection and analysis of all relevant data for a product at each stage of production, installation and assembly, is also the task for the wind power industry. Each wind turbine consists of hundreds of bolted connections. The guideline VDI / VDE 2862 Sheet 2: describes the "minimum requirements for application of fastening systems and tools – Applications in the plant construction and mechanical engineering and for the flange connections in components under pressure boundary. The guideline VDI/VDE 2862 Sheet 2 categorizes this following application areas:

Screw the Category A: High risk assessment, risk to life and limb or the environment.
Screw the Category B: Mean risk assessment, dysfunction / plant shutdown
Screw the Category C: Low risk assessment, Uncritical

Various bolt-connections in the wind power sector includes at least to Category B, if not to Category A. Smarttorc is in the sense of Industry 4.0, a mobile, for construction sites intelligent hydraulic Boltingsystem consisting of a process and documentation pump ECO2Touch in combination with hydraulic torque wrenches for the collection, analysis and control of all bolting-runs. The Smarttorc system provides customized, flexible and application-oriented process and documentation solutions due to its modular design. For safety reasons, it is possible to work without using Reaction-Arms by using one of five possible Bolting-elements. No matter it with or without Reaction-Arm, each tightening procedure is reliably controlled by the ECO-2Touch and every single tightening process logs tamper-proof in written and graphic form. It meets all the VDI / VDE 2862 – Part 2 required technical minimum requirements for nuts and bolts- category A and B as:

- Directly measured control variable (eg torque, angle, elongation, pressure)
- Directly measured monitoring variable (eg torque, angle, elongation, pressure)
- Control variable and monitoring variable must not be identical.
- Make fastening results available for further processing
- For reliable results, the discontinuous operation of the hydraulic wrench is determined by a monitored Control logic of the ECO2Touch.
- Any single result per bolting-run is evaluated with OK or NOK. These data (actual value and the control value) in the form of text and graphics will be automatically generated as a pdf and made available.
- With rotary angle sensors on hydraulic torque wrenches the measurement procedure for detecting the control or the control number is so designed that the safety claim is met.

Monitoring of the hydraulic Smarttorc-screw system:

- Self-test of all system components related to control and monitoring variables
- Redundant design of measuring sensors for direct acquisition of control and monitoring variables. This can also be achieved by means of a plausibility check.
- The digital interface of the fastening system control and manufacturing control system must allow for detection of malfunctions in signal communication.

The following bolting-methods can be handled and controlled:

- Torque-controlled tightening
- Torque-controlled-rotation angle monitored tightening
- Torque-controlled-yield-monitored tightening
- Torque-angle method
- Yield-controlled method
- Yield-controlled rotary angle-monitored tightening
- Bolt Load-controlled tightening by using one of a five possible Bolting-elements

REMAINING LIFE TIME PROGNOSIS OF WIND TURBINE SUPPORTING STRUCTURES

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1. Introduction

In the future market framework of renewable energies – especially in the case of wind energy – economic operation strategies will become more and more important. This is true for micro- and macro-economic reasons and the latest political developments in the renewable energy market confirm that development. The application of special monitoring and testing systems in that framework contributes to economic optimized operations strategies. The prediction of remaining service life times of wind turbine supporting structures is one important module.

This contribution is concerned with a methodological approach to calculate the remaining life time of the prestressing steel in the tower structure depending on deflection collectives (EC 2). The prestressing steel in wind turbine supporting structures has a high risk potential, which is also known from bridge buildings. In a first step the acceleration data from the SCADA-sensors at the tower top is validated and transformed into a deflection collective. Under concern of the geometrical deflection forms of the tower structure the stress variation of the prestressing steel bars were analysed. Using the relevant S-N-curves and the Palmgren-Miner law the occurred fatigue damage is calculated, which enables the comparison to the design load cycles and finally an extrapolation leads to the remaining service life time of the supporting structure.

POSTER 4: SIMULATION I (WIND TURBINE) DEWEK 2015

THE DYNAMIC RESPONSE OF WIND TURBINE BLADES UNDER THE TRANSIENT LOADS

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Abstract

With the penetration level of wind power on electric network increasing rapidly all over the world, the interactions of the wind turbines and grid network become more obvious. The dynamic loads of the wind turbines have a strong impact on the electricity quality. The grid faults cause transients not only in the electrical system, but also in the wind turbine mechanical system. The faulty of the grid for example voltage sag can excite the mechanical vibration of wind turbines structure.

This paper investigates the dynamic responses of the wind turbines blades under the transient loads based on the FEM. The blade is modeled as a cantilever, considered the torsion around pitch axis. The natural frequencies of the blades were calculated, the influence of rotor speed, blade azimuth and pitch angle on the natural frequencies were analyzed. Also, the dynamic responses of the wind turbines blades under the fundamental transient loads(Impulse excitation, ramp excitation, rectangular pulse, triangular pulse, half-sine pulse) were analyzed.

The results show that there is maximum peak value in the shock response spectrum, it depends on the ratio of transient time and natural frequency. For the longer transient, amplification factor is mainly decided by the increments of the velocity. For the shorter transient, amplification factor is mainly decided by size of the impulse. The vibrations excited by the transients have also impact on the aerodynamic and structural loads of wind turbines.

CHARACTERISTIC LOAD CASES FOR ROTOR BLADE DESIGN

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1. Introduction

The development of a new rotor blade may have various restraints and requirements that are unique for each customer. Whether the blade shall be for a new turbine design or a retro fit, the process is usually very similar. It is an iterative process, starting with a preliminary aerodynamic design with estimated structure properties which is used for load calculations. The loads are then used to improve the aerodynamic and structural blade design which requires further load calculations and so on. While the results of this iterative process are converging, the time for load calculations increases. Especially since the wind industry demands multibody calculations with ever increasing details and design guidelines require an increasing amount of load cases to be simulated.

Based on a database of load sets for about 60 rotor blades ranging from 1.5MW to 8MW, this paper investigates by simple statistics the contribution of each load case group to the ultimate loads used for the rotor blade design. It shows that certain load case groups gain importance with increasing reference wind speeds and others can be neglected for rotor blade design. Results are available for loads based on IECed3 and GL guidelines separately.
This study shall give insight to the loads engineers in the possibilities of reducing calculation time by focussing on specific load case groups during the early design stages.

2. Results

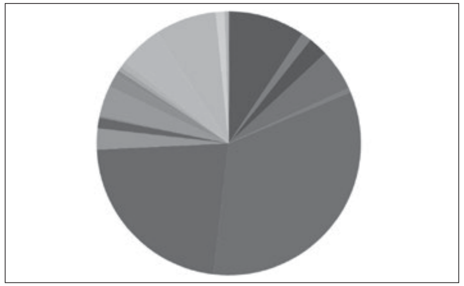

Fig. 1: GL guidelines (2003/2010)

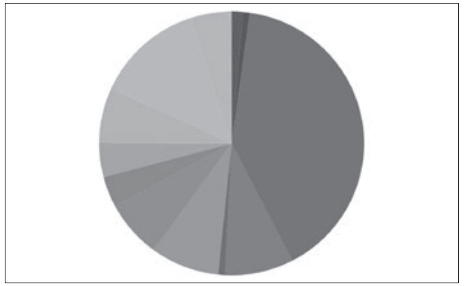

Fig. 2: IECed3 guidelines (2003/2010)

Figure 1 shows that load case groups 1.5 (EOG with grid loss, blue field) and 1.6 (EOG50, red field) are dominating the ultimate rotor blade loads. In IECed3 guideline it is group 1.3 (ETM, turquoise field), see fig.2

The complete paper features a ranking of load case groups and further investigation by wind classes.

VERTICAL AXIS WIND TURBINES FROM A CERTIFICATION POINT OF VIEW

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1. Motivation

1.1 Vertical vs Horizontal Axis

Vertical axis wind turbines (VAWT) are characterized by rotors with rotating axes perpendicular to the wind stream.
In contrast to horizontal axis wind turbines (HAWT), VAWT's do not require yaw equipment, have a drive train at ground level and present a low noise level [1]. Nevertheless, their lower efficiency and the intricate aerodynamics together with important fatigue problems for blades observed in the past persuaded the industry to concentrate efforts on HAWT's.

Within the last few years, though, VAWT's have gained renewed interest as a potential competitive wind turbine design in two strategic areas where classic HAWT present significant disadvantages

a) kW-size VAWT in built environments, where the wind is characterized by frequent and often rapid changes in direction and speed [2].
a) MW-size VAWT offshore, since a lower centre of gravity provides additional stability [3]. Moreover VAWT's might be more convenient to upscale, compared to HAWT's

1.2 Towards VAWT standards

This recent interest has not been accompanied by a development of corresponding standards.
Current certification guidelines and standards are founded on HAWT technology. However the assessment of VAWT's requires considering new specific aspects. Some of the most relevant are: load case catalogue needs to be tailored on VAWT designs, control and protection systems need to be redefined and the design of rotor blades as well as mechanical and electrical components has to be consequently adapted.

2. VAWT Aerodynamics

From a certification point of view, one of the main challenges is the need of a proven numerical code for loads and response analysis. In contrast to HAWT's, the swept surface of a VAWT is fully three-dimensional. Blade elements do not only operate both unstalled and stalled but they also encounter their own wake and those generated by other elements as they rotate [4].
In order to get a better understanding of this process a thorough analysis of the structural loads produced in VAWT's is being carried out at DNV GL. The main objective of the study is a code-to-code comparison of the loads obtained considering different aerodynamic models, such as double-multiple streamtube model or actuator cylinder model, and different VAWT designs. These results are then compared with measurements.
In the paper the results of the load comparison as well as its consequences for the setup of a VAWT load catalogue will be presented.

3. References

[1] Sutherland, H.J et al.: "A Retrospective of VAWT Technology", SAND2012-0304 (2012).
[2] Smith, J. et al.: "Built-Environment Wind Turbine Roadmap", NREL/TP-5000-50499 (2012).
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ADVANCED AIRFOIL SIMULATIONS BASED ON REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS

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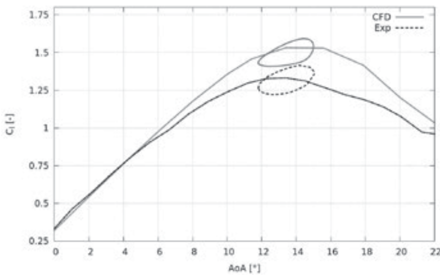
1. Two-dimensional Airfoil Simulations

The linear range of the lift coefficient of an airfoil can be predicted very well by most simulation techniques. For high Reynolds numbers and low angles of attack the drag coefficient can be captured as well. More advanced are simulations of airfoils at higher angles of attack, where stall and separation can appear. Fast methods based on potential theory are usually not precisely enough, but even computational fluids dynamics (CFD) based on the Reynolds-Averaged Navier-Stokes equations (RANS) need special turbulence models to predict transition and early stall. Methods with a higher precision, such as Large Eddy Simulations (LES), are computationally more expensive.
In this work the RANS approach is used for the prediction of lift and drag of airfoils at high angles of attack. The results are compared with experimental data.

2. Airfoil in dynamic stall

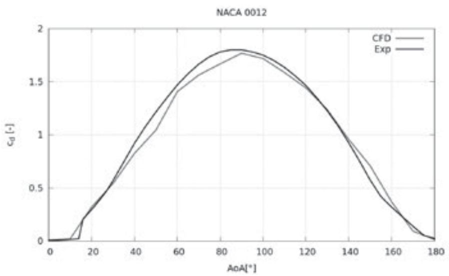
Due to a poor prediction of the static stall behaviour it is a challenging task to simulate an oscillating airfoil via the unsteady RANS approach. The NACA 63 415 airfoil was experimentally tested in a wind tunnel by Bak et al.[1].



The simulations are not able to capture the static polar in the stall region completely. There is a deviation of approx. 15 %, which is a common difference for many RANS turbulence models [1]. The deviations of the dynamic stall are in a similar range, so it is possible to include this error into further considerations.

3. Airfoil at high angle of attack

Beside the linear range and the stall behaviour of an airfoil, it is of interest how RANS can model the flow over airfoils for higher AoA.



The measurements were done by Sheldahl et al. [2] and a good agreement of numerical and experimental drag coefficients can be seen.

4. References

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[2] R.E. Sheldahl, P. C. Klimas. "Aerodynamic Characteristics of Seven Symmetrical Airfoil Sections Through 180-Degree Angle of Attack for Use in Aerodynamic Analysis of Vertical Axis Wind Turbines", Sandia National Laboratories, SAND80-2114, 1981.

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THE DYNAMIC STABILITY ANALYSIS OF WIND TURBINES UNDER DIFFERENT CONTROL STRATEGIES

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Abstract

The control strategies have essential influences on the dynamic stability of modern wind turbines. This article presents a theoretical investigation on this topic. The investigation is motivated by a vibration measurement of 4 wind turbines with capacity of 1.5MW in a wind farm. The mechanisms of control strategies influencing the dynamic stability have been discussed and the stability enhancement by means of time delay τ in pitch control is investigated. The results show that the optimum control of rotational speed for maximizing energy capture below rated power can improve the dynamic stability by suppressing the axially unstable vibrations of wind turbines. At above rated wind speed, the control mode of fixed-speed variable-pitch can cause unstable axial vibrations of the wind turbines; variable-speed variable-pitch can suppress the unstable vibrations. Additionally an appropriate time delay τ in pitch control can effectively enhance the dynamic stability of wind turbines.

The optimum time delay τ_{opt} is $\frac{1}{2}T$ (T is the period of the axial vibration of wind turbines).

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CONSIDERATION OF FLEXIBLE GEARS FOR DETAILED GEARBOX ANALYSIS

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For the design and dimensioning of complex drivetrains including gearboxes, many CAE-programs are normally used nowadays. These include in particular programs of the Finite-Element-Method (FEM) and the Multi-Body Simulation (MBS). Both approaches have in common that the real system is discretized and that equations of deformation and/or of motion are created and solved numerically. Therefore, both programs can be used for load calculation, whereby the Finite-Element-Method generally concentrates on static and the Multi-Body Simulation on dynamic load cases.
In order to ensure an optimum static and dynamic design of the gearbox, likely consisting of several helical, bevel and planetary gear stages, each single stage needs to be simulated in both programs simultaneously. Especially because in the MBS single gearwheels are modeled as rigid bodies, which means that they do not have single eigenmodes. The contact stiffness between two gearwheels is modeled by a spring-damper element representing the compliance of the gearwheel body and the single tooth (linear) as well as the Hertzian Pressure (non-linear). This approach shows for several application areas very good results compared to measurements.
But a rigid gearwheel approach implies some simplifications and limitations, which make it inappropriate for detailed NVH analysis. Especially gearwheel eigenmodes and the torsional deflection of the single teeth can have a big influence on the system behaviour. For the gearbox shown in figure 1, neither MBS nor FEM can provide an efficient analysis process. The former neglects the gear wheel flexibility, the latter demands an inacceptable computational effort (memory and CPU time).

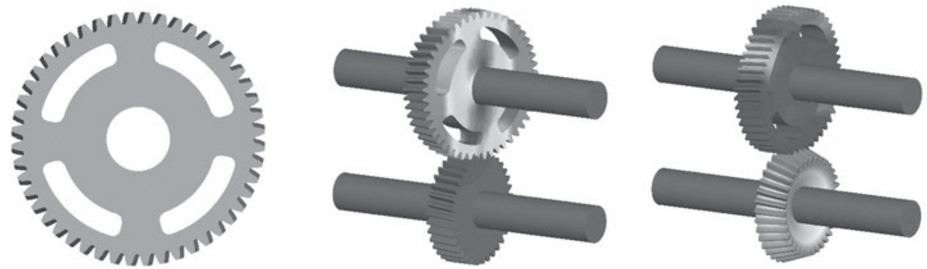

Fig. 1: Geometry and critical eigenmodes of a acoustically optimized gear

In this article, a new MBS approach for flexible gears will be presented. It combines highly accurate results with low computational effort. By means of several examples of helical and planetary gears, the approach will be validated with the FEM. Then, the necessity of considering gear flexibility and the dynamic interaction with the surrounding system will be highlighted.

RELIABLE VALIDATION OF LOAD SIMULATION MODELS

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1. Introduction

1.1 Basic Validation Method

Every complex simulation is an approximation to the reality. To determine the accuracy of simulated results, a validation with measured values is required. The most common validation method is to verify the simulation tool or model, prepared for a specific wind turbine type with a subset of measurements obtained from the corresponding prototype. This leads to a greater confidence in the predicted extreme and fatigue loads.

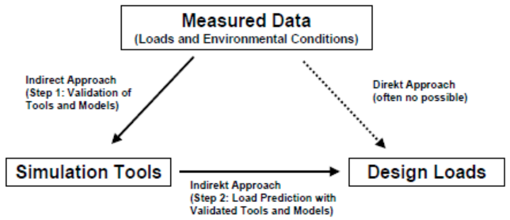

Fig. 1: Validation of design loads [3]

A second, not often used approach is to compare the whole simulated load set directly with the measured data. The basis for this method is to measure and compare the full set of loads (see fig.1).

1.2 Specific needs of designer

Each wind turbine will be further developed over time. Often components will be modified to increase the efficiency in the light of experience acquired. These modifications can be structural related like different rotor blades or tower types, or operational related like different control and safety philosophies or systems. In case of slight modifications the overall turbine behaviour remains the same but at the same time a major modification can lead to a complete different turbine behaviour and therefore loads, too.

To understand if the simulated loads are still trustworthy, following questions should be known and answered:

1) What are validation relevant modifications of wind turbines?
2) Which measurements are needed to validate the simulation model?
3) Is the already validated simulation model still applicable for the modified turbine variants?

2. Proposals for Validation Methods

2.1 Approach according standards or guidelines

Measurements shall be made on a wind turbine that is dynamically and structurally similar to, but may differ in detail from the original turbine design [1]. The validation will be handled by a comparison between the measured data of loads and Eigen frequencies and simulation results considering the environmental conditions.

2.2 Approach for turbine variants

To determine that an already made validation is still valid for different turbine variants, indicators to represent the difference of the dynamic behaviour are needed. A so called indicator is often defined as the change in the first Eigen frequency (EF) of turbine components. The percentage amount of this change is of decisive significance and needs to be determined. For a more detailed picture, a set of indicators like coupled EF, statistical properties [2], load quantity, comparison of time series (frequency and time domain) and a consistency check of the fatigue characteristics [3] can be necessary.

3. References

[1] IEC 61400-22 Wind turbines – Part 22: Conformity testing and certification
[2] IEC 61400-13, Wind turbine generator systems – Part 13: Measurements of mechanical loads
[3] DEWI GmbH and DEWI-OCC GmbH "A Guide to Design Load Validation"

WINDSAGE: COMBINING MULTIPLE NWPS WITH DEEP NEURAL NETWORKS (DNN) FOR AN IMPROVED WIND POWER FORECAST

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Jon Meis*, Achim Strunk*, Jeremy Sack*

1. Introduction

In view of the growing fraction of wind power in Germany and other countries, accurate wind power prediction is becoming more and more important. We are currently running an operational wind power forecast based on the GFS-4 and HIRLAM numerical weather prediction (NWP) models that achieved a mean accuracy of about 4.1 % day-ahead nRMSE for Germany in 2013. It is based on DNNs trained on historical wind and power forecasts (Fig. 1).

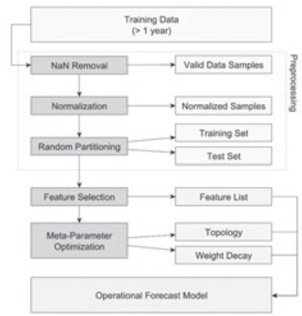

Fig. 1: Training scheme for the current DNN-based wind power forecasts.

2. The WindSage Model

It is a well-known fact that a combination of many different NWPs tends to improve wind power forecasts, yet how to optimally combine these models is up for debate. In WindSage, we will extend our current model by combining up to eight deterministic NWPs and two ensemble NWPs using DNNs aiming at an increase in both the deterministic as well as the probabilistic forecast quality. To this end, the set of NWPs will cover a cascade of global to meso-scale models offering a wide range of different spatial/temporal resolutions, assimilation techniques, model physics and parameterizations in order to ensure the addition of independent information. This requires a stringent data reduction for the neural networks' input vector, which we aim to achieve not only by standard techniques like PCA, but also by means of state-of-the-art machine learning techniques like Parameter-exploring policy gradients (PGPE, [1]), that are already part of our comprehensive Learn-O-Matic toolbox [2]. The massive computing power needed for this endeavour is provided by Graphics Processing Units (GPU) that speed up training and meta-parameter optimization by up to two orders of magnitude.
In addition, the horizontal resolution of WindSage will be enhanced compared to the old model, making it possible to predict single grid nodes in addition to control zones or entire countries.
We will describe the methods used in more detail, show preliminary results of our NWP model combination experiments, and discuss how WindSage and related data driven methods benefit from improved measurements and NWPs.

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AN ACCURATE WIND RESOURCE ASSESSMENT IN COMPLEX TERRAIN USING NUMERICAL SIMULATIONS

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1. Introduction

As the size of wind farms increases, a marginal improvement in a power prediction during the design process can lead to a significant difference in the annual energy production. Bechmann et al. [1] performed a blind comparison for the wind measurement over natural complex terrain. The most successful model showed 10% of the mean error which is higher than wind farm designers would accept [1]. One main reason for such deviations was due to difficulties in controlling upcoming turbulence. Therefore, the goal of this study is to present a method for an accurate prediction of wind resource in complex terrain using numerical simulations with an advanced turbulence inflow condition.

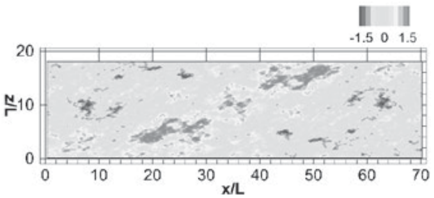

Fig. 1: Contour of the u-velocity component.

2. Methods and preliminary results

For numerical simulations, the FLOWer will be used, which is a finite-volume based and block structured solver. This code was developed by the German Aerospace Center (DLR), and has been applied in many wind turbine simulations, such as Schulz et al. [2]. An eddy resolving approach will be adopted for the turbulence modelling, e.g. DES.

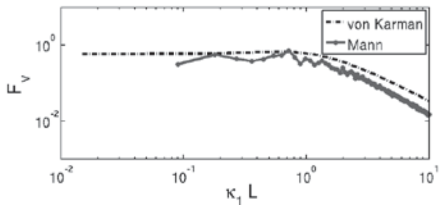

Fig. 2: 1-D spectrum of v-velocity component.

To generate atmospheric turbulence, the Mann's uniform shear model [3] is adopted. The input parameters for uniform shear turbulence are L=15(m), $\alpha\varepsilon^{2/3}$=0.078($m^{4/3}s^{-2}$) and Γ=3.5, where L is the length scale, ε is the rate of dissipation of turbulent kinetic energy. The domain size was set to $L_1 \times L_2 \times L_3$ = 70L × 8L × 18L and resolution was 256 × 64 × 128. The subscripts 1,2,3 indicate the three directions and correspond to x,y,z respectively.

Fig. 1 shows a contour of the u-velocity component. It is evident that the inclined structures towards the x-direction exist due to the shear, and no visible repeating structure is observed. Fig. 2 shows 1-D spectrum of v-velocity component and it is compared with von Karman's model spectrum [3]. The spectrum by the Mann model predicts a general trend well: a plateau for $\kappa_1 L < 1$ and decay rate for $\kappa_1 L > 1$, but the magnitude is slightly under-predicted compared to the target spectra.

The generated inflow turbulence will be applied on the flow over an idealized hill, and compared with experimental data. Details of numerical descriptions for a flow over a hill, e.g. resolutions, numerical scheme, turbulence model, will be provided in the paper.

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EFFECTS OF ROTOR INDUCTION ON THE PROPAGATION OF DISTURBANCES TOWARDS WIND TURBINES

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1. Introduction

The evolution of turbulent structures as they approach a wind turbine is critical in order to link turbine loads to free-stream turbulence. Secondly, knowing the coherency and timing for the arrival of such structures is required for future use of Lidar for feed-forward control [1].
In the present work, a 5 beam pulsed Lidar has been mounted on a 5 MW XEMC Darwind turbine to characterise rotor induction and its effects on the propagation of disturbances towards wind turbines.

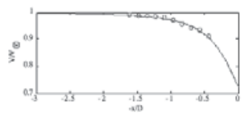

Fig. 1: Free-stream velocity as a function of the distance from the rotor (circles), together with fitted wind model to determine the induction parameter.

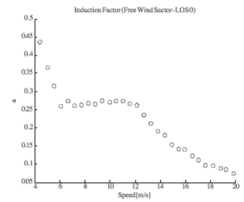

Fig. 2: Evolution of induction parameter "a" as a function of free-stream wind speed.

2. Characterisation of the induction effect

Due to energy extraction, the inflow decelerates by a factor "a" (typically a=25%) upon approaching the rotor [2]. The Lidar's central beam is aligned along the longitudinal axis to characterise "a" for different wind speeds (Figure 1). Figure2 shows the fitted induction for different wind speeds, including the expected drop in axial induction when the wind turbine pitch control starts to limit the power (after rated wind speed of 12m/s).

3. Effects of induction on turbulence intensity and convection speeds

For different average wind speeds, the longitudinal wind speed variance stays constant with the distance to the rotor: the observed increase of TI is thus due mainly to the decrease of longitudinal wind speed.
Convection speeds were derived from two cross-correlation methods. The main conclusions are as follows:
Spatial-temporal methods provide higher estimates than spectral methods. Both estimated speeds appear to follow linearly the free stream wind speed, with a deviation at high wind speeds (Fig. 3)
Unlike the longitudinal wind speed, the convection speed does not slow down when approaching the rotor
Higher turbulent frequencies are convected at higher speeds

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ADVANCED USE OF MCP METHODS TO CORRELATE SHORT TERM MEASUREMENT DATA WITH LONG TERM DATA

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1. Introduction

1.1 Need for a new use of MCP methods

High hub heights of wind power plants cause special requirements to energy yield calculations with measurement data – especially when it comes to bat-protection, shadow or noise loss calculations. Short term data from SODAR or LIDAR measurements give information about wind conditions in hub height and above. Long term data like reanalysis data (e.g. MERRA) mostly represent near surface wind conditions (e.g. 50m agl.) with lower gradients in the diurnal variation of the wind speed.
However, short term measurements of few months provide not enough information to predict the long term annual wind conditions in high hub heights accurately. Thus, a new approach is presented, where this lack of information is substituted by a new binning of the data.

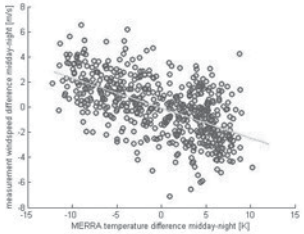

Fig. 1: Scatter of daily temperature v.s. wind speed difference

1.2 Methodology and test set up

Different to the "traditional use" the data is not binned sectoral for the correlation with long term data, but by the MERRA temperature difference between midday and night. The basic assumption is, that the temperature as well as the wind speed has a diurnal and annual variation and both correlate (see Fig. 1). Additionally the data is separated in three hourly bins.
Different MCP methods (e.g. Total Least Squares, Variance Ratio, Speed Sort Algorithm) are compared to a "traditional" Reference Method (sectoral+diurnal variance ratio).
At first the algorithm is tested and compared to a two year measurement at 128 m agl and – second – a one year 50m measurement. The latter was combined with short SODAR data and compared to wind turbine production data.

2. Insights and Results

The met mast data in the second test is projected to hub height via correlation with the SODAR data first. Not every bin is filled properly with short measurements. With low correlation coefficients or few data in a bin the corresponding regression factors are rejected and replaced.
The algorithms works better the longer the measurement period is. With the new algorithm the VR method has in most cases the best results.
With short measurement periods the RM shows differences of the projected to the measured mean (two year) wind speed up to 10 %, the new algorithm up to 5 %.
Due to a more realistic representation of the annual and diurnal cycle of the wind speed the new method predicts the power plant energy yield more accurately, as the second test shows.
The methods are further tested with additional data and similar results.

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ROTOR IMBALANCE DETECTION AND MITIGATION

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1. Introduction

Improving the reliability of wind turbines is a key aspect for the success of any wind power plant. To this end, health monitoring techniques may be used to detect incipient failures and to reduce the impact of maintenance on the overall wind turbine operational cost [1].
Unbalances, caused for example by ice formation or pitch misalignment, may lead to decreased power output and cause vibrations, which eventually affect fatigue life and may possibly trigger shut-down/start-up sequences. For modern large and very large wind turbines, possibly located in remote areas, any aerodynamic unbalance is an important issue, as a machine could operate in unbalanced conditions for days or weeks before a suitable maintenance can be scheduled. In this scenario an appropriate control action, aimed at reducing the undesired effects of rotor unbalances irrespectively of their origin, has to be considered.
This paper describes a method to detect rotor unbalances and a specifically designed new individual pitch controller aimed at mitigating the related vibrations.

2. Detection

It is well known that an unbalanced multibladed rotor transfers loads at the 1xRev (1P) frequency to any non-rotating part of the machine. Accordingly, an unbalance coefficient can be introduced to monitor the appearance of 1P frequencies, defined as the amplitude of 1P measured quantities (loads or accelerations, depending on the availability of sensors) normalized by the dynamic pressure. Such coefficient, when averaged over a suitable time window (typically 10 minutes), is a good indicator of unbalances, as it is independent of changes in wind shear, wind misalignment and other operational conditions. For example, Figure 1 demonstrates the effects on the unbalance coefficient (based in this case on the hub nodding moment) of the pitch misalignment of one of the blades of a 3MW wind turbine. The results are based on high-fidelity simulations conducted with an aeroservoelastic multibody code [2].

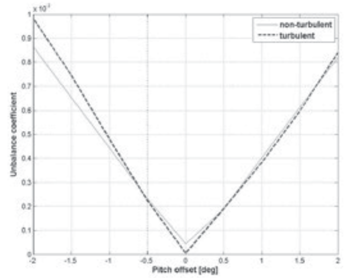

Fig. 1: Effect on the unbalance coefficient of a blade pitch misalignment

3. Mitigation

Loads caused by rotor asymmetries cannot be reduced by a standard individual pitch control action and therefore a specific approach is needed to reduce them. In this paper, a control algorithm based on a modified Coleman transformation, specifically tailored to rotors with asymmetries, is designed and tested in various conditions, including icing and pitch misalignment. Numerical simulations show that the novel control algorithm can reduce the loads caused by rotor asymmetries.

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LASER BASED GEOMETRY MEASUREMENT OF ROTOR BLADES

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1. Aerodynamical Imbalance

1.1 Introduction

Since the middle of the 1980's wind-energy underwent a steady growth world wide to become the second biggest source of economically exploitable renewable energy after Hydro.
As development continued the capacity of the turbines grew and so did their dimensions. This resulted in growing structural loads and growing sensitivity to all kind of rotational imbalance.

1.2 Mechanical Impact

The most sensitive part of the turbine is the rotor. All dynamic forces which load the structure are caused and transmitted by the rotor which has to withstand these loads itself.
Limits for system deviations are given in the Type Test Approval. Any asymmetry in the rotor geometry exceeding these limits results in dynamic imbalance. Subsequently the system is charged with undefined vibrations i.e. unknown load spectrums.
Due to the difficulties in measuring the correct alignment the problem has long been neglected.

1.3 Measuring Method

The measuring method is based on the idea of scanning the surface of the rotor blades while operation and comparing the so processed profile shapes.

By using high end laser sensors in a frequency range of 1000–2000Hz the detected deviation of the shapes provides an accurate gauge of misalignment and thus blades can be precisely adjusted on the spot.
Apart from the angular misalignment that can be detected the system measures the tower movement and uses it as reference to assess the impact of the imbalance
Results of more than 200 measurements have shown that about 60% of operating turbines are affected. 20% out of these are in a severe condition and would have to be stopped or adjusted immediately.

2. Measurement values and Accuracy

Measurand	Resolution
1 Relative pitch angle*	+/- 0.2°
2 Radial segmentation*	+/- 0.2°
3 Tracking Accuracy Tip**	+/- 10 mm
4 Twist angle*	+/- 0.3°
5 Tower movement	+/- 10 mm
6 Tower clearance	+/-10 mm
* Deviation of mean value; ** Blade tip	

The given accuracy results from various test series at turbines with precision incremental angular sensors and distance test series. However, accuracy is part of ongoing system analysis in the frame of quality assurance and preventive error avoidance.

A NEW APPROACH TO ELIMINATION OF AERODYNAMIC IMBALANCES OF WIND TURBINES

S. Bartholomay*, M. Hillman*, T. Rische*

1. Introduction

Increased vibrations of wind turbines lead to accelerated wear of all components of the machine. Vibrations are caused amongst others by mass and/or aerodynamic imbalances. Nowadays mass imbalances are relatively well controlled by manufacturers. However, aerodynamic imbalances are often underestimated and their negative impact increases with growing rotor diameters: on numerous wind turbines analysed by cp.max about 50% showed significant axial vibrations caused by aerodynamic imbalances. These imbalances are either caused by erroneous pitch angles or by deviations in the twist along the blades to one another. In order to determine and reduce these imbalances a photometric measurement was developed and its accuracy was validated by different methods.
However, relying only on the photometric measurement is not always sufficient for very large blades as very small angle deviations or errors in twist lead to severe imbalance issues. Therefore, a new approach was developed which is detailed in the presentation.

2. Determination and Elimination of Aerodynamic Imbalances

2.1 Measurement

A photometric measurement is conducted with the rotor being positioned at the Y-position, hence one blade pointing downwards. After adjusting a special profile marking at a given radius position, pictures are taken by means of DSLR camera. Thereafter, a CAD software is used to determine the blade pitch angle, figure 1.
Thereby the relative angle offset between the blades can be determined. Furthermore, with the twist angle provided by the manufacturer the absolute angle can be calculated.

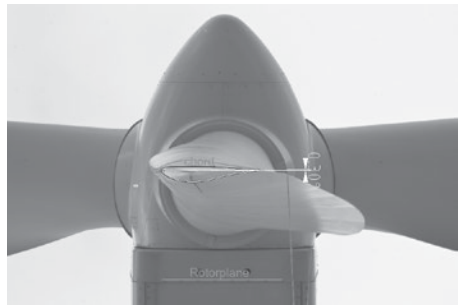

Fig.1: Analysis of the photometric measurement

2.2 Elimination of Aerodynamic Imbalances

Adjusting the blade pitch angle according to the measured deviation is the standard way to reduce aerodynamic vibrations. However, at very large rotor diameters, measurements have shown that this procedure is not always sufficient to eliminate vibrations. Therefore, a technique was developed where an iterative process using test angles are employed to achieve a low vibration level. This iterative process is monitored by a vibration analysis by means of accelerometers installed in the hub of the turbine.

3. Conclusion

The standard procedure of minimizing axial vibrations according to the photometric measurement has proven to be sufficient for a large variety of wind turbines. However, for very large turbine blades the new approach had to be used to find the optimum pitch angle. This procedure was conducted on numerous turbines, leading to different blade pitch angles of the three blades to one another, but thereby to a very low vibration level.

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STRUCTURAL VIBRATION MEASUREMENTS AT WIND TURBINES USING VIDEO-BASED TRACKING

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1. Introduction

Load and vibration measurements at wind turbines (WT) are necessary for design simulation validation. But as well during WT operation it is useful to measure and analyse the vibrational behaviour, e.g. verifying the tower's natural frequency for WT where the rotor speed or blade passage may excite resonance. For special cases, measuring the clearance between blade tip and tower is of interest. Furthermore, a share of 45% of WT is affected by rotor imbalance (RI) limit exceedence, which causes accelerated fatigue through increased loads. RI is determined through measuring the axial, lateral and torsional tower-nacelle vibrations, typically using accelerometers installed in the nacelle. This requires time consuming climbing up, equipment craning and installation. Therefore, video-based vibration measurements are promising to save time and have the advantage that in an 2D image vibration can be tracked at several points in two linear directions and as well rotation.

2. Challenges of video tracking at WT

In order to get an accurate quantitative vibration amplitude result several challenges have to be addressed to measure e.g. tower-nacelle vibration:
Availability of suitable tracking points: Tracking can be performed only if there are objects in the image, which can be reliably found and are large enough to allow sub pixel accuracy. Installing special markers or lights is very time consuming but an option in special cases.
Weather and illumination conditions: Once travelled to the site, low clouds, rain or fog hinder taking a video or at least blur images, while they not disturb a measurement using accelerometers. Changing light and moving shadows disturb evaluation. Applying filters during image processing may help but may falsify obtained amplitudes, especially if sub-pixel accuracy is required. Wind-induced camera vibration is an issue.
Image resolution and quality: If e.g. for RI assessment, the amplitudes at the rotor's rotational frequency are of interest, the target amplitudes are 2...20 mm, depending on the individual RI limit. The resolution should be an order lower, despite WT hub heights above 100 m and large general nacelle movements. This requires a high-quality camera, a low distortion lens with suitable focal length and an accurate camera positioning.
Image calibration: To transform amplitudes from Pixel into real world mm.
Yaw correction: For evaluation of nacelle vibration, a reliable coordinate transformation from the steady camera system to the yawing nacelle system is necessary. Blocking the yaw produces falsification by inclined inflow.
Simultaneous tracking of several objects: This reduces significantly the evaluation time. Order analysis using a generated rotor speed signal is necessary to remove falsifying rotor speed fluctuations. This requires reliable tracking of re-appearing objects at the rotor.
Storage of large data: A 20 min full HD video has a size of 2 GB while a parallel acceleration measurement with 4 sensors has a file size of 4 MB.

3. Examples of application

For uncertainty investigation, simultaneous measurements with accelerometers were carried out at a special test stand (rotor speed 1...30 rpm, acceleration 0.5...10 mg, magnification 0.1...5.0 Pixel/mm). During root cause analyses natural frequencies of blade and tower were measured, showing e.g. that the latter was outside the certified frequency range. Nacelle amplitudes of more than 1 m during gusty full-load operation and shut-downs were documented. Air intake housing vibration was detected. RI-related amplitudes in the range of 1 mm were successfully resolved at WTs with hub height above 100 m. Video-based strain gauge calibration for load measurements was performed, too.

ON THE CUP ANEMOMETER WORKING CONDITION MONITORING

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1. Introduction

As a cup anemometer loses performance, due to the normal wear and tear process or to sudden incidents such as lightning, the wind speed measurement given by the instrument diverges from the real wind speed. This error can be translated into a wrong wind turbine operation or inaccurate data when studying the energy production of a specific geographic location, causing a negative impact on the revenue. Around 30% of mast-mounted anemometers return for recalibration far from normal operational conditions [1]. See Fig.1.
Today, the only solution for keeping anemometers in a proper working condition is to check them through frequent calibrations [2]. Calibration-on-the-field procedures are also a cost-effective solution for reducing anemometer maintenance and the number of recalibrations [3,4]. A new methodology to monitor cup anemometer status when working on the field is under development at the IDR/UPM Institute. This method could help to optimize the maintenance of these sensors, if it is implemented on the corresponding data loggers. At present (i.e., October, 2014), lab-research at has been carried out with good results [5–7], testing-on-the-field being programmed to start during November 2014., in collaboration with Kintech Engineering.

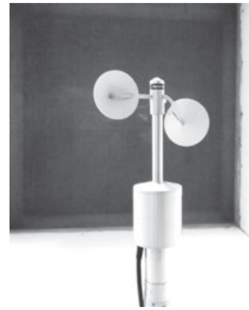

Fig. 1: Vector Instruments A100 LK cup anemometer calibrated at the IDR/UPM Institute after a service period on the field.

2. Cup anemometer status based on Fourier analysis

Fourier decomposition allows anomaly detection on the sensor, as any asymmetric effect on the rotor-shaft system (dirt, damage, wear and tear...) is reflected mainly on the first term of the rotational speed Fourier series decomposition, see Fig. 2. Results are very promising [5–9].

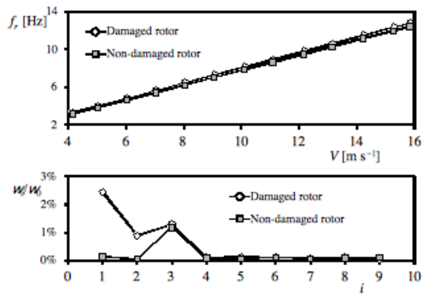

Fig. 2. (Top) Calibration curves of a Vector Instruments A100 LK cup anemometer with damaged (Fig. 1) and non-damaged rotors. (Bottom). Rotational speed Fourier decomposition terms of the anemometer with bot damaged and non-damaged rotors.

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ANALYTICAL AND EXPERIMENTAL ANALYSIS OF THE WAKE EFFECTS ON TURBINES IN WIND FARMS TO OPTIMIZE THE OVERALL ENERGY PRODUCTION.

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1. Introduction

A wind turbine in the wake of another turbine produces less energy caused by the velocity deficit in the wake, an effect which is well known and studied. The velocity deficit is caused by physical circumstances during the energy extraction of the wind. Early research showed that the thrust coefficient (Ct) of the rotor is a good indicator to calculate the velocity deficit in the wake. Jensen [1] developed a simple mathematical model for this issue which allows the wind velocity at a given distance behind a turbine to be easily predicted. This model is widely used to calculate wind farm AEPs (e.g. WAsP). The thrust of a wind turbine is calculated by the flow of masses and the velocity change in the actuator disk layer. Pitch regulated wind turbines reduce the thrust and power by changing the pitch-angle of each blade when reaching the rated wind velocity. Using the pitch regulation before the rated wind speed is reached will result in a loss of power and thrust but leads to higher wind speed in the wake which could lead to a higher energy production for the rest of the wind farm. [2] This study examines the circumstances under which the gain of energy production in the wind farm due to pitch regulation is bigger than the loss of energy, and if it is possible to significantly increase the total AEP of the wind farm.

2. Methodical approach

In the first step of the research a calculation of power curves for the turbines is done by an aero-elastic simulation with a model of the wind turbine in FLEX 5. Calculations of wake loss are carried out with several separation distances between turbines of 3-8 times the rotor diameter. For the estimation of the AEP, a model of a wind farm in Northern Germany is built and calculated with WAsP. To estimate the best configuration of pitch angles, the maximum power of all concerned turbines is calculated for each pitch angle at each wind speed. The result is a new optimized power curve for each turbine where the pitch angle, power and thrust value at each wind speed may be different. With those power curves the AEP is calculated using WAsP. In a final step the turbines in the wind farm are configured with the calculated power curves and it is measured if the effect behaves as predicted.

3. Results

The results of the calculation of the power curves show that the Ct-value can be reduced almost by half while the Cp-value is reduced by a quarter, if the pitch offset is 5 degrees. Considering wake effects between two turbines separated by 3 diameters, wake losses in both concerned sectors could be reduced by 15.5% and 18.4%, leading to an AEP increase of 7.6% and 9.0% respectively in these sectors. The differences are due to slightly different Weibull coefficients for each sector and indicate that the wind distribution is an important factor for the optimization of a farm.

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MET MAST BASED MODEL FOR TURBULENCE ASSESSMENTS IN CENTRAL AND SOUTHERN GERMANY

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1. Introduction

1.1 Initial situation

A series of wind farms under development have become subject to legal actions in Germany because these are extensions to existing wind turbines under different ownership. As these extensions would harm the energy production due to wake effects, there is significant motivation to fight such developments. In many cases, this question boils down to what distance between the wind turbines needs to be kept, and not whether the turbines are impermissible at all. The objective parameter for keeping certain distances would be the induced turbulence intensity ("TI") that is caused by the new wind turbines, and whether the allowable turbulence intensity by certification for the existing wind turbines is exceeded.

1.2 Motivation for research

Effective turbulence intensity as defined according to IEC 61400-1 [1] is comprised of the ambient turbulence intensity, its standard deviation and the induced turbulence intensity. Since ambient TI can only be measured by means of a suitable wind measurement, this information is not available for most wind farm sites in Germany. Therefore, the decision on whether wind turbines are spaced too close together or not is based on assumptions that may be far from reality.

2. New data provides input

2.1 Evaluation phase

TÜV SÜD reviewed a series of tall tower met masts (120 m to 140 m) in central and southern Germany with particular focus on ambient turbulence intensity and its standard deviation depending on wind speed, height above ground level and topographic features. The following figure shows the representative turbulence intensity for the research met mast "Nordbayern" over a 2 year measuring period at 100 m AGL compared to the normal turbulence model ("NTM") of IEC 61400-1 ed 3.

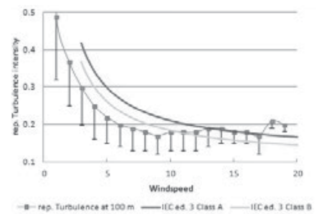

Fig. 1: Representative turbulence and standard deviation of the ambient turbulence (error bars) in comparison to the NTM class A and B for research met mast "Nordbayern"

2.2. Results

Figure 1 just shows one observed deviation from the NTM, but which in its shape occurs very often in or nearby forested sites. However, the "dip" around 5 to 8 m/s as well as the "rebound" around 10 to 15 m/s can be quite different in magnitude and sign. Implicitly, this also shows that no two sites are alike. TÜV SÜD will show an empirical approach to model the "dip and rebound" shape of the curve as well as an appropriate magnitude as so to be more accurate regarding the answer to the question of spacing wind turbines in that area.

3. Reference

[1] IEC 61400-1 ed. 3: IEC 61400-1:2005: Wind Turbines – Part 1: Design Requirements

ASSESSMENT OF LIDAR-CORRECTION FOR WIND MEASUREMENTS IN COMPLEX TERRAIN

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1. Background

Remote sensing devices, especially Light Detection And Ranging (LiDAR), lately experienced a technical development that allows them to deliver high quality wind measurements as needed for energy yield assessment. While there is a lot of comparison of LiDAR to cup anemometer in flat terrain and offshore with very good correlation, in complex terrain due to the different flow situation the use of remote sensing technique and processing needs improvement. With a LiDAR the wind vector is derived from volume measurements at different times and different locations which actually demand a homogenous and stationary wind field that is not given in complex terrain.

2. Aim

In a measurement campaign together with WPD and DEWI in the "Schwäbische Alb" existing guidelines to LiDAR measurement in complex terrain shall be approved. A complex terrain correction provided by the LiDAR manufacturer will be tested against results derived by data of a met mast.

3. Approach

The LiDAR will measure wind speed and wind direction for about three months in the vicinity of the met mast. Measurement setup and data assessment will be done according to the conventions of the new guideline (FGW-TR6). The outcome of the energy yield assessments based on the different methods (LIDAR, LIDAR+correction, met mast) will be presented and discussed.

4. Acknowledgement

The data from the meteorological mast is kindly provided by WPD for evaluation.

THE FIRST MEASUREMENT CAMPAIGN OF MITSUBISHI ELECTRIC'S WIND LIDAR IN EUROPEAN TEST SITE

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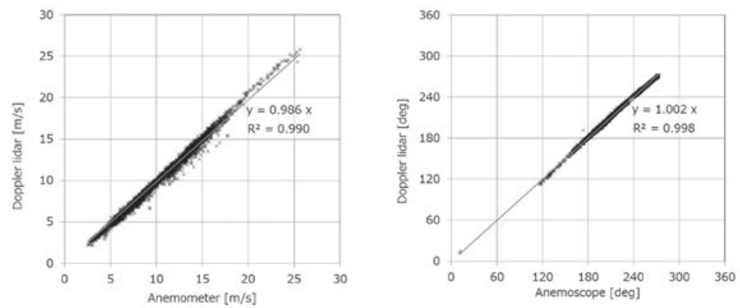
1. INTRODUCTION

The wind lidar has been attracting the attention as a sensor for wind resource assessment because the wind velocity and direction at each altitude with remotely can be measured.
We have developed the wind lidar from late 1990's. For applying our compact lidar to wind resource assessment, we had improved on beam scanner to high speed by using optical switch, and had developed the new signal processing functions of the automatically tuning of measurement parameters which depends on the atmospheric conditions [1]. Furthermore, we performed the first measurement campaign at Energy research Centre of the Netherlands (ECN) test site.
In this paper, we report the result of improved lidar first time performance at ECN.

2. LIDAR PERFORMANCE

The measurement period is from 29th October 2013 to 13th January 2014. In this campaign, we compared the wind velocity data measured by the lidar with that measured by the anemometer installed on the IEC compliant meteorological mast. The cup anemometer and vane anemoscope installed on the 100m altitude of meteorological mast are used.
Figure 1 shows the comparison results of (a) wind velocity and (b) wind direction with 10 minutes averaged. For the wind velocity, a linear regression slope of a=0.986 and the linear regression correlation coefficient R2=0.990 were obtained. It shows a good agreement between the lidar data and meteorological mast data. Furthermore, these results meet the NORSEWInD (NORthern SEas Wind Index Database) standard [3].
The availability of the lidar data is assessed in the measurement sector per measurement height, and is shown table 1. The data availability of 95.9 % was achieved at 100 m height when include the cloudy and rainy conditions.



(a) Wind velocity *(b) Wind direction*

Fig. 1. Comparison results of ldiar and meteorological must data.

3. SUMMARY

We had developed the wind lidar for applying to wind resource assessment. The feature of improved lidar is the function of automatically tuning of measurement parameters which depends on the atmospheric conditions. We had demonstrated the first measurement campaign at ECN. The comparison results meet the NORSEWInD standard [2].

4. REFERENCES

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[2] C. B. Hasager, et al., Remote Sens., 5, pp. 4280-4303 (2013).

HIGH-AVAILABILITY WIND LIDAR SYSTEM ADAPTING TO ATMOSPHERIC ENVIRONMENT FOR RELIABLE WIND RESOURCE ASSESSMENT

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1. INTRODUCTION

The efficient wind resource assessment needs (a)cost-effective measurement, (b)many wind information(ex. vertical profiles) (c)stable data obtaining, and so on. Recently, for realizing above needs, the wind lidar is expected to apply to the wind resource assessment. However, conventional wind lidar systems1 have an issue in the instability of performance, since signal-to-noise ratio (SNR) related to measurable range depends on the atmospheric condition such as the aerosol density, turbulence, and so forth.
To overcome this issue, we developed the the wind lidar system with the adapting parameters to various atmospheric conditions, which automatically realize the best performance under the given atmospheric condition for obtaining high data availability. Here, we present the above mentioned functions and those advantageous effects of new product2.

2. SYSTEM CONFIGURATION

In the previous wind lidar system, the constant parameters, for example, (1) focal range and (2) number of accumulation that can contribute improving the measurable range are used for each observation.
On the other hand, in this new system, the system controller derives the best parameters of (1),(2) automatically using obtained range profile of SNR, line-of-sight wind velocity, spectral shape, and user's request.

3. ADVANTAGEOUS EFFECT OF ADAPTIING PARAMETERS FUNCTION

In this section, some examples of advantageous effects for parameter tuning are shown as follows.

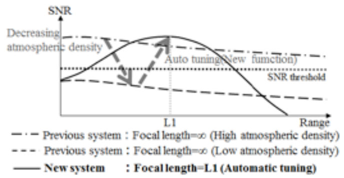

Fig. 1 Schematic explanation for the effect of the focal range tuning.

(3-1) Optimization of focal range

Figure 1 indicates the case of decreasing SNR related to the measureable range depending on the atmospheric condition. The chain line, dash line, and solid line correspond to the cases of (i) infinity focal range under high aerosol density condition, (ii) infinity focal range under low aerosol density condition, and (iii) focal range of L1 under low aerosol density condition, respectively. The dot line indicates the SNR threshold for correct signal detection. It is shown that when the aerosol density becomes low, there are no available data for all ranges if the focal range is set at infinity. However, this lidar recognizes this situation automatically by the analysis of SNR, and changes the focal range to the point for realizing the best performance, which is the longest measurable range in many cases.

(3-2) Optimization of signal processing parameter(number of accumulation)

In this function, accumulation number is automatically tuned. For example, when SNR becomes lower than the threshold in a specific range, this situation is recognized in the SNR analysis, and the spectral accumulation continues until enough SNR can be confirmed. This processing can be done for each range independently.

4. SUMMARY

We introduced a new products of wind lidar system with automatic adapting parameters. This functions provide the lidar performance which fits best to the user's needs under various atmospheric conditions. Therefore, It could contribute the stable measurement for wind resource assessment. In this presentation, the effectiveness of those functions with real data will be shown.

5. REFERENCES

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TURBINE MOUNTED PULSED LIDAR FOR PERFORMANCE VERIFICATION IN COMPLEX TERRAIN

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1. Introduction

Operational use of LiDAR (Light Detection And Ranging) systems in simple terrain has been extensively proven: ground-based LiDAR´s are going through IEC standardization for power curve measurements while turbine mounted pulsed LiDAR´s with two lines of sight have been demonstrated to be suitable for power performance testing [1] and are now industrially used.
Complex terrain is another challenging topic. Using fully equipped meteorological masts to measure wind turbine performance in complex terrain is a costly, time consuming and technically challenging task. Turbine mounted LiDARs like the Wind Iris are seen as a promising solution to deliver accurate answers in complex terrain [2] while bringing operational advantages, as they are always measuring in front of the turbine.

Fig. 1: Wind Iris multi-range pulsed LiDAR installed on turbine roof

2. Instrument validation

The accuracy of the nacelle mounted LiDAR is validated against a ground-based WINDCUBE v2 LiDAR located ~300m away. A high quality correlation between the two units is obtained in common measurement volume, which corresponds to the wind sector where the turbine is facing the location of the ground based LiDAR.

3. Results

We present results obtained in a measurement campaign performed with a Wind Iris pulsed multi-range turbine mounted LiDAR installed on a turbine located in a complex terrain and forested wind farm area. Using simultaneous measurements in all sectors at short and long ranges, several topics are investigated such as the effect of wind sector and turbulence intensity on wind turbine power curve, yaw and nacelle transfer function. It is shown that the Wind Iris allows for faster evaluation as more wind sectors become available.
The overall conclusion is that a multi-range turbine mounted LiDAR is a serious and competitive tool to investigate wind turbine performance in complex terrain, by providing a wide number of answers and a simplified and cheaper set-up.

4. References

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[1] GWU-Umwelttechnik GmbH, Germany; [2] Avent Lidar Technology, France; [3] Verbund GmbH, Austria;
[4] juwi Energieprojekte GmbH, Germany; [5] Uptime Engineering GmbH, Austria

ASSESSMENT OF TURBULENCE MEASUREMENTS FOR OFFSHORE TURBINE TESTING WITH NACELLE BASED LIDAR

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1. Introduction

Nacelle-based LiDARs are increasingly used for offshore wind turbine testing, as a much lower cost alternative to a meteorological mast. In particular, for power curve validation and loads assessments, the measurement of the flow's turbulence may be required. The objective is of this work is to assess the performance of commercially available nacelle-based LiDARs with respect to measuring wind speed variances and turbulence intensities.

2. Theoretical framework

In a first part of this work, the effect of the LiDAR measurement process and of the determination of wind speed second orders moment from individual LiDAR beams is analytically decomposed. Several wind reconstructions methods are compared with respect to their expected sensitivity to external flow parameters, such as turbine yaw misalignment and atmospheric stability. In particular, the measurement process is compared to that of a cup anemometer.

3. Validation with measurements

Next, the data from several measurement campaigns are used in order to verify experimentally the theoretical findings. The results show that using a turbulence estimate based on individual LiDAR beams, the correlation between wind speed variance derived from the LiDAR and that of the cup anemometers shows an encouraging correlation and slope compared to the mast reference. Differences can be attributed to the filtering of small turbulence scales by the LiDAR probe length.

4. Conclusion

In conclusion, for a nacelle based LiDAR, a method based on the use of turbulence components from individual beams allows deriving a robust estimate of the longitudinal turbulence facing the wind turbine. On the other hand, the assessment of transverse and vertical component is much more challenging. Additional field testing and advanced simulations should be carried out to confirm the above findings.

CLASSIFICATION AND SENSITIVITY ANALYSIS OF TURBINE-MOUNTED AND FLOATING LIDARS

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1. Introduction

Lidar (laser anemometry) is becoming increasingly accepted for many tasks throughout the wind industry following its first use on a wind turbine in 2003 [1]. As its use becomes more widespread, high priority must be placed on understanding any sources of uncertainty. A methodology has been established in [2] for ground-based lidar profilers, in which the sensitivity of the lidar measurements to various atmospheric parameters is quantified. Here, we extend this approach to cover two further areas of lidar use: turbine mounted and floating platforms.

2. Classification analysis

As remote sensing devices such as lidar have become more widely recognized as valuable tools for making wind measurements, Annex L of [2] has been written to ensure the traceability of remote sensor measurements to National Standards. It describes a procedure to assess the uncertainty contribution of those measurements to power curve evaluation through a two part test of the sensor: a classification test and a verification test.
In the classification test, the sensitivity of remote sensor measurements to environmental parameters such as temperature, wind shear, etc, is assessed. Example units of that type of sensor are deployed close to a tall IEC-compliant meteorological mast for an extended period of time, during which there should be a wide range of environmental conditions. The differences in measured wind speed between the remote sensor and the mast are considered as a function of one environmental parameter at a time. An accuracy class for the remote sensor is derived by combining the results of these sensitivity analyses, suitably extrapolated to cover a similar range of conditions as those used in the classification of cup anemometers.

2.1 Turbine-mounted lidar

Turbine-mounted lidar is a powerful tool with potential for performance monitoring and active control. We have analysed data from a number of trials in which forward-looking ZephIR Dual Mode (ZDM) lidars have been mounted on the nacelles of large wind turbines. We have performed, as far as is possible, a classification assessment following the methodology devised for ground-based remote sensing devices. Our aim is to give a preliminary indication for these devices, as a step towards increasing confidence in their performance under a wide range of conditions, leading towards wider adoption in future.

2.2 Floating lidar

Floating lidars are a very promising cost-effective method for offshore resource assessment. The classification and sensitivity analysis has much in common with that of ground-based profiling lidars, but with the additional requirement to take account of sea state as well as atmospheric parameters. Possible sea-state conditions to take into account include wave height and frequency, and tidal state.

3. Results

The analysis for the turbine-mounted case is hampered slightly by the lack of mast data to upper tip height. Nevertheless, the analysis shows minimal sensitivity of the results to environmental variables. Similarly, the floating lidar data shows excellent immunity to platform motion induced by a diversity of sea states.

4. References

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LIDAR USE CASES FOR THE ACQUISITION OF HIGH VALUE DATA SETS

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1. Introduction

Remote sensing in general and lidar in particular provide a much more extensive set of measurement techniques than were previously utilised by offshore wind power professionals. These allow wind conditions to be characterized in much more detail than was previously possible. Effective exploitation of these new opportunities requires a structured approach to the design of measurement campaigns involving lidar to ensure high value data are acquired. If lidar is only used to fulfil requirements previously met by more limited instrumentation then the full value offered by lidar will not be realised. Unnecessary limitations in the value of lidar data can be avoided by considering lidar use cases when designing measurement campaigns.

2. Implementation

The International Energy Agency (IEA) Wind Energy Task 32 has been set up to capture and codify the wind industry's experience and expertise with respect to the use of lidar in wind power applications. Key work packages within this task have adopted a "lidar use case" framework as the basis for describing the many lidar techniques available. This considers:

- The combination of the lidar methods being employed,
- The data requirements that can be fulfilled using the data sets these methods make available, and
- The situations and circumstances in which the performance of these procedures can be verified in terms of measurement accuracy.
- A valid lidar use case entails the implementation of a method where:
- The accuracy of the data is understood under the circumstances in which the method is used and
- The data set fulfils a purpose or requirement that arises sensibly in the context of the broader project aims and objectives
- As a result it should be possible to calculate a quantifiable return on investment and integrate the acquisition of the data into financial models with greater transparency.

3. Conclusion

When designing a lidar campaign one must consider:

1. The data requirements
   a. What does my project need? What question am I asking?
   b. Can I quantify the benefit of fulfilling these requirements?
2. The lidar method
   a. Have I adequately documented the measurement procedure?
   b. Does the method fulfil my data requirements?
3. The situation in which the data are acquired
   a. Do I understand the accuracy of the method under the circumstances in which it is used?
   Is this accuracy enough for the application?
   b. Can I perform a complete and unbiased uncertainty analysis?

This is necessary to ensure one can:

1. Select the appropriate lidar measurement methodology for a given project data requirement with reference to the circumstances under which the data are being acquired
2. Define a complete, unbiased, open and transparent approach to measurement uncertainty with respect to lidar measurements such that IEA bankability criteria are fulfilled
3. Undertake offshore measurements that enable fuller characterisation of the complex offshore wind conditions that impact the productivity and longevity of offshore wind power assets

A COMPARISON OF 2- AND 5- BEAM NACELLE MOUNTED LIDAR MEASUREMENTS ON AN OFFSHORE WIND TURBINE

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1. Introduction

Nacelle mounted lidar methods in which the lidar is facing forward to acquire measurements upwind of the rotor have been adopted recently as a means of obtaining wind data for power curve tests or wind turbine control offshore.
Two different measurement schemes have been implemented simultaneously using two lidars on the nacelle of an offshore wind turbine. The results are compared with respect to key concerns regarding the selection of nacelle mounted lidar methods and the possible measurement biases that may be incurred.

2. Implementation

Two scanning lidars were installed on the nacelle of wind turbine AV07 in Alpha Ventus Offshore Wind Farm for one month late in 2013. Each implemented a specific measurement configuration. Concurrent data were acquired from each of a 2-beam and 5-beam set up. The sensitivity of the measurements to the configuration was investigated in relation to vector and scalar averaging schemes. This was done by comparing the wind speed results.
2-beam configurations are widely used with nacelle mounted lidar acquiring wind data upwind of an offshore wind turbine. The 2-beam set up is adequate for horizontally homogeneous wind. However, in more complex flow measurement ambiguity can occur. The same basic raw underlying radial velocity measurements along the 2 lines of sight can arise for both a change in wind direction and transverse inhomogeneity due to turbulence but with no change in wind direction.
This ambiguity is conventionally overcome by adopting a vector averaging scheme, in which the radial velocities are averaged over a 10 minute averaging interval before horizontal wind speed and direction are extracted from the results. This contrasts with scalar averaging, in which wind speeds and directions are acquired first and then averaged over the 10 minute averaging interval. In the presence of fluctuations in wind direction these methods can lead to different results.
These differences are potential sources of bias in vector averaged data compared to scalar averaged data more representative of cup anemometry. A 5-beam set up was implemented with a second lidar device to investigate this, as the 5-beam set up is less sensitive to the ambiguities under consideration.

3. Conclusion

Scalar and vector 10 minute average wind speeds obtained concurrently using 2- and 5- beam nacelle mounted lidar were compared to explore the possibility of wind speed bias in 2-beam nacelle mounted lidar measurements due to wind direction fluctuations within the averaging interval.
This bias was detected and quantified with reference to the magnitude of the wind direction fluctuations. In this presentation different nacelle mounted lidar methods are discussed and their advantages and disadvantages compared. The bias arising due to choice of beam geometry and averaging scheme is evaluated. Recommendations regarding the implementation of nacelle lidar methods for power curve tests and wind turbine control are offered.

A DETAILED ANALYSIS OF SHIP-LIDAR MEASUREMENTS WITH COMPARISON TO FINO1

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1. Introduction

Even if most implementations of floating-lidar systems consist of buoys as platforms, for special applications the flexibility and mobility of ship-based implementations is required.
Ship-lidar measurements have been performed and presented in [1,2]. Within the EERA-DTOC project, measurements in proximity to FINO1 and Alpha Ventus wind farm were performed [3].
In this paper we will present a detailed analysis of the motion influences and correction methods for the measurements, both differing compared to buoy platforms. The results will be compared to FINO1 offshore meteorological mast.

2. Measurement set-up

2.1 Measurement system

The ship-lidar system consists of a Leosphere WindCube® V2 and a combination of different motion sensing devices, see Fig. 1. Data correction is performed in post-processing. The ship-lidar is installed on the support vessel LEV Taifun, with a length over all of 41.45 m and approx. 1.8 meters draught.

Fig. 1: Ship-lidar system installed on the top deck of the support vessel LEV Taifun.

2.2 Ship-motion and motion correction

Under normal conditions, ship motions are dominated by the ship speed over ground (sog) and course over ground (cog). Using smaller ships – like support or service vessels – and under average sea states, also roll motion can be a significant influence.
As a consequence, motion measurement and motion correction method have to be adjusted for the measurement and also differ to lidar-buoy measurements.

3. Comparison ship-lidar vs FINO1

Within the EERA-DTOC project, three measurement campaigns were performed. Goal of the third campaign was a validation measurement in proximity to FINO1 under different ship motions.
Here the theoretical influences of the motions will be compared to the measurements. Especially different kinds of corrections, using line of sight measurements or vectorial results as well as different motion information, will be compared to FINO1.
As a result, the mandatory correction for this kind of measurement as well as the precision compared to a met mast will be stated.

4. References

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REPRESENTATIVENESS OF SHORT-TERM WIND PROFILE MEASUREMENTS WITH REMOTE SENSING DEVICES AND CONSIDERATION OF SEASONAL EFFECTS

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Especially in Germany hub heights much above 100 m become more and more usual for new planned wind farms. On the other hand reference wind turbines often have a significantly lower hub height and therefore the estimation of the vertical wind profile has high uncertainties. Short term measurements by remote sensing devices (RSD), as now introduced in the revision 9 of the TR6 [1], provide a way to assess and verify the wind profile between the hub height of the reference WTG and the planned hub height.
In this contribution the limits and prerequisites of such short term measurements will be presented. Special focus will be given on the variation of the wind profile over the time of the day and over seasons and an analysis of its influence on the results. Furthermore, a directional variation of the wind shear because of differences in orography, roughness and general weather conditions will be investigated. The representativeness of the measured wind profile will be checked by comparing short term periods with full years periods of several full year RSD measurements
The representativeness of the measured wind profile has to be validated and in case that it is not representative the wind profile has to be corrected. DEWI has developed and uses two different methods for the correction of seasonal effects, the seasonal correction based on the solar zenith angle and the wind gradient correlation [2]. The seasonal correction method has been further developed to include the dependency on thermal stability.
In this work seasonal effects have been tested on remote sensing measurements with duration of a whole year for varying input periods. The input periods has been varied in length (of 3 months and 6 months) and season (winter, summer, intermediate). We will present the effectiveness of the seasonal corrections methods, address uncertainties and determine the limits of these procedures.

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ADVANCED INTEGRATION OF OFFSHORE WIND ENERGY INTO THE GRID SYSTEM BY POWER TO GAS

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1. Introduction

Sustainable energy sources play a more and more leading role in future energy generation. Operating offshore wind turbines under economic considerations puts to the challenge that wind forecasts and actual output do often differ widely. This makes it difficult to participate in the free electricity market and destabilizes the electric supply network without appropriate countermeasures.

2. Objects

This paper investigates whether the combination of a wind farm with an energy storage based on methane can provide relief. The basic idea is to compensate the differences between forecast and actual output of offshore wind energy with the help of the storage. To accomplish this, a concept for intelligent scheduling, i.e. the predictions derived from nominal supply, is developed. This enhanced scheduling is based on forecast wind data, corrected by a factor derived from a temporal analysis of the deviation of forecast to actual value with an added impact to control the storage level. Furthermore, the obtained concept for scheduling is analysed using a set of real data of a given wind farm and optimized experimentally. Moreover, the paper also examines how such a system of wind turbine and storage meets the criteria for participation in the balancing energy market and how such participation in return affects the system. A consideration of incomes attainable by this system using the developed method of optimized scheduling under conditions of free electricity market participation completes the paper. Some commercialization scenarios concerning off-shore wind-farms are discussed. The focus is set to energy-exchange trading combined with offering control reserve (secondary control reserve (SCR) or minute reserve (MR)) or only offering control reserve without participating in energy exchange trading.

3. Results

The main advantage of such a power to gas storage system is the still existing natural gas grid in Germany and also large storage capacities. Thus the storage system and the power source can be spatially separated. Furthermore gas storages in the form of gas holders can be built at all locations, in addition gas storages with extremely large capacities up to several billions of m3 can be realized in salt or granite formations.

FACING THE EUROPEAN PERSPECTIVE: REVISION OF WIND POWER UPSCALING

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1. Introduction

1.1 A European electricity market

In February 2011 the member states of the European Union (EU) agreed on creating an internal energy market for the whole EU [1]. This market requires the estimation of both energy production and energy consumption within the trading zone in near real-time. Since regulations and standards are very diverse across Europe estimations must be based on relatively small data sets. In wind energy so-called 'uspcaling' algorithms are used.

1.2 Estimating regional wind power production

Upscaling algorithms are based on information from a set of reference wind farms, which are passed to an upscaling model. The model computes an estimate of the total production by using different statistical methods, such as for instance regression models and artificial neural networks, and additional meteorological data.

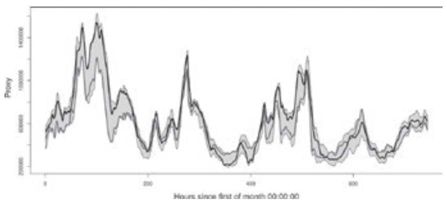

Figure 1: Time series of modelled European wind energy production for January 2012; the black line denotes the total production, green line is the estimate based on k=2 reference wind farms: the range of estimates based on k ϵ [2,50] is shown as shading.

The first step, however is the selection of reference wind farms. Investigations show, that the accuracy of the estimate strongly depends on the chosen number of reference wind farms k (see figure 2). In fact, the accuracy increases exponentially with k (not shown). Several approaches exist for the selection scheme (for an overview see [2]), which are – until now – mainly applied to smaller regions. For larger areas such as Europe no operational scheme for the selection of reference wind farms and no operational upscaling model exist.

2. Revised upscaling algorithms

The explanations stated above emphasize the need for revised upscaling algorithms – including schemes for the selection of reference wind farms – to estimate the near real-time wind energy production in the future European energy trading zone.
In this study we summarise the challenges, which one has to bear when developing upscaling algorithms for whole continents. Approaches to handle data deficits, e.g. introducing artificial turbulence to wind speed data and statistical downscaling, are presented.
Furthermore, we show a comparison of different reference wind farm selection schemes and results from investigations of the effect of turbulent as well as extreme wind on the estimated total European wind energy fed into the grid.

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4. Acknowledgements

This work is part of the Integrated Research Programme on Wind Energy (IRPWind, www.irpwind.eu). It has received funding from the EU under grant agreement No. 609795.

PROBABILISTIC WIND FARM GROUP FORECASTING USING BAYESIAN MODEL AVERAGING

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1. Introduction

For operational purposes forecasts of the lumped output of a group of wind farms spread over a larger geographic area will often be of interest. It is well documented that a better choice than to simply sum up all sites within an area is to use a model that also is able to take advantage of spatial smoothing effects. Forecast. Here, Baysian model averaging BMA is used to improve the weighting of the single site forecasts for the estimation of the expected lumped output. In addition BMA deliver information for a probabilistic forecast.

2. Bayesian model averaging

Bayesian model averaging (BMA) is a statistical post-processing method for producing probabilistic forecasts from ensembles, which in this case is the single site forecasts. Raftery et al. [1] showed how BMA can be used for statistical post-processing of forecast ensembles, producing PDFs of future weather quantities. The BMA predictive PDF of the future wind power production of a group of wind farms is a weighted average of single-farm PDFs, where the weights can be interpreted as posterior probabilities and reflect the single site forecasts' contribution to overall group forecasting skill over a training period.
In [2] the BMA method was found to produce accurate probabilistic forecasts for group mean wind speeds, but when attempting to forecast wind power production the shape of the wind to power transformation curve caused the PDFs to be either too wide or to give consistent under-predictions.

3. A case study for data from Norway

BMA is applied here to a set of synthetic (modelled power output data based on wind speed measurements and forecasts) for 43 stations in Norway, separated into 7 groups. The BMA scheme was performed for each group. Fig.1 gives as example a section of the outcome for one group, showing various confidence limits for the 24h forecasts group power and the lumped power according to the wind measurements. It can be remarked, that the BMA procedures produces fairly accurate confidence intervals

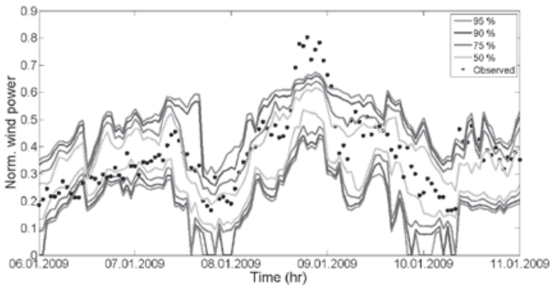

Fig. 1: Sample confidence interval for five days in January 2009 for group power output, showing good coverage except for a peak at 09 Jan.

3. References

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ECONOMICAL RISK SIMULATION OF MAINTENANCE CONTRACTS OF WIND FARMS

J. Hauschild, D. Althaus*, J. Liersch**

1. Introduction

1.1 Service and maintenance in the wind energy industry

In future the service and maintenance of wind energy plants will become more and more important [3] – the yearly growth rates are about 10% in the wind energy industry. Furthermore there is a trend to full maintenance contracts over the entire life cycle – it is obvious that the technical management is becoming more professional.
The maintenance and the associated O&M-costs of wind farms are estimated at a level above 30% of the investment [4]. The competition in the O&M-services requires an economic assessment and optimization of service and maintenance contracts with respect to the technical and economic risks.

1.2 Risk assessment of O&M-service contracts

For a holistic, realistic risk assessment of O&M-service contracts the challenge is to combine different information with each other. Beside the technological risk of component or system failures, which can influence safety issues, there are many economical risks as well. These can be e.g. the downtime of a system, the need for spare parts or different prices during a long maintenance period. These economical risks are directly connected with technological risks. As part of the risk assessment, analytical methods go here often to their limits. The ability to integrate information of different types and levels is often difficult or impossible.

1.3 Risk Assessment with the aid of the Monte-Carlo-Simulation

The risk simulation using Monte-Carlo-Method is a very viable solution. Monte-Carlo simulation is a computer-based simulation method, which is applied in many areas and continues to find distribution [1], [2]. Based on a variety of simulated random events complex systems, contracts and other relationships are mapped and valid appreciated. On the identification of these simulated events complex analytical formulas are bypassed and the simulation objects "real" played out. The possible combinations of the simulation here are unlimited. The implementation in various software environments (MS Excel VBA to specific CAS) is possible.

2. Expected Results

The aim of this paper is to present the approach of a risk assessment of O&M-service contracts. To this end, a straightforward example from the field of maintenance of wind turbines will be presented – the linkage of technical and economic information will be presented. From the results the management is able to evaluate and to optimize contracts.

3. References

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[2] Plinke, F.; Althaus, A.; Braasch, A.; Meyna, A. Combination of technological and economical risk assessment using the Monte-Carlo-Simulation. Tagungsband ESREL 14, 14.-18. September 2014.
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REGIONAL CONTRIBUTION TO THE WIND ENERGY DEVELOPMENT IN GERMANY – ANALYSIS OF SELECTED ADMINISTRATIVE DISTRICTS UNTIL END OF 2014

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Normally the wind energy statistics in Germany shows only the wind energy development for the whole of Germany and the federal states. In the analysis of 2011 [1] for the first time there was a closer look into the installations in each district and it shows, that the development mainly takes place in certain districts (Tab. 1 and Fig. 1) [2].

District Landkreis	Federal State Bundesland	Inst. Capacity (MW) Inst. Leistung (MW)
Dithmarschen	Schleswig-Holstein	154,1
Nordfriesland	Schleswig-Holstein	147,2
Rhein-Hunsrück-Kreis	Rheinland-Pfalz	132,0
Mecklenburgische Seenplatte	Mecklenburg-Vorpommern	130,8
Rostock	Mecklenburg-Vorpommern	130,4
Alzey-Worms	Rheinland-Pfalz	120,2
Vorpommern-Greifswald	Mecklenburg-Vorpommern	71,7
Aurich	Niedersachsen	69,5
Cloppenburg	Niedersachsen	69,1
Paderborn	Nordrhein-Westfalen	66,4

Tab. 1: TOP-10 districts in 2013

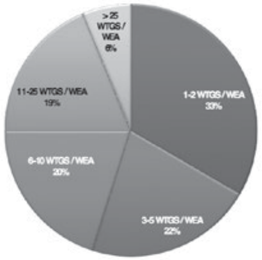

Fig. 1: Share of the districts related to the quantity of the installed turbines in 2013

Based on the collected installation data of more than 24 years and the upcoming result of 2014, the presentation will show the development over the years in some selected districts. This includes not only the number and installed capacity, but also the average capacity and WTGS class related to the rotor diameter will be presented.

The districts are selected on their total installed capacity at the end of 2014 and also include some with repowering projects.

Selection process and analysis will be in January/February 2015 and so no current data could be presented in this abstract.

References

[1] Ender, Carsten; Wind Energy Use in Germany – Status 31.12.2011, DEWI Magazin 40, 30 -43, February 2012
[2] Ender, Carsten; Wind Energy Use in Germany – Status 31.12.2013, DEWI Magazin 44, 35 -46, February 2013

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WIND ENERGY DEVELOPMENT IN GERMANY – ANALYSIS OF THE DEVELOPMENT IN THE DIBT WIND ZONES UNTIL END OF 2014

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Normally the wind energy statistics in Germany shows only the wind energy development for the whole of Germany and the federal states. As an addition to this there was some time ago an analysis for the costal and inland regions in which the federal states where put together in three different sectors.

Based on the collected installation data of more than 24 years and the upcoming result of 2014, the presentation will show the development in the wind zones according to the DiBt classification [1] for some selected years or time periods.

This includes not only the statistical data like number and installed capacity of the wind turbines, but also the average capacity, rotor diameter, hub height, specific power installation and WTGS class. As an addition to this a map will be presented, showing the installations in the wind zones.

Selection process and analysis will be in January/February 2015 and so no current data could be presented in this abstract.

Fig. 1: Wind zones in Germany [1]

References

[1] DIN EN 1991-1-4/NA picture NA.A.1, taken from http://www.derdichtebau.de/windlasten.28072.htm

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LAND REQUIREMENT VALUES FOR WIND FARMS

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In Germany, new wind turbines are normally operated in areas which are specially designated for the use of wind power. It is usually regulated in regional development plans that the construction and operation of wind turbines outside of these "suitable areas" and "priority areas" is not allowed.

Since many years DEWI has performed several studies to analyze the potential for the further development of wind power in different regions in Germany, e.g. in Lower Saxony and in Saxony-Anhalt. The investigations were based on a survey for an up-to-date stocktaking of current wind energy use, for the planning of new projects and for designating new areas for wind farms.

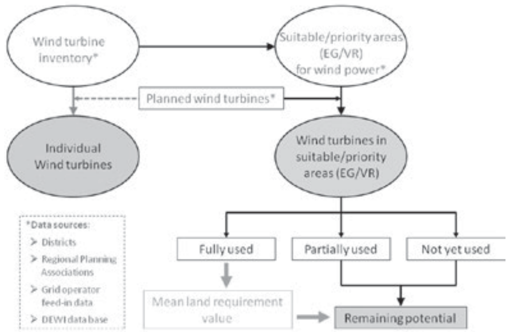

Fig. 1: Overview for estimating the remaining potential for wind energy in the investigation area [1]

The estimation of the medium-term development of wind energy use is based on the remaining potential identified in the investigation area. Remaining potential is available when an area has not (or only partly) been used for wind turbines. The basis for the analysis is the so-called "land requirement value" (see Fig. 1).

This contribution examines the variation of the land requirement values in different regions and the observed development based on the studies in the last decade.

Aspects like the tendency of an increasing density of wind turbines in wind farms (i.e. reduction of wind turbine spacing) in recent years and the influence of different wind turbine sizes are discussed. Furthermore, the investigation considers how the different regulations in the federal states in terms of the determination of border lines for the designated areas affect the required assumptions for the land requirement values.

References

[1] Plenty of potential still available for wind energy use in norther Saxon-Anhalt, DEWI Magazin No. 45, August 2014

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WIND FARM DEVELOPMENT IN TURKEY

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In this presentation, history of the 3000 MW wind farm development of Turkey will be given. From the Turkish Wind Atlas prepared in 1989 to date the efforts to develop wind farms in Turkey will be highlighted. Initiatives by the stakeholders, opportunities, potentials and barriers for further development of wind energy in Turkey will be analyzed.

ADDITIVE MANUFACTURING AND SPARE PARTS LOGISTICS IN OFFSHORE WIND ENERGY

A. Barz[1)], K. Lange[2)], H.-D. Haasis[3)]

1. Introduction

From a technical point of view, 3D-Printing, Rapid Prototyping, Rapid Manu¬facturing and many other synonyms can be summarized as Additive Manufacturing (AM). AM is "... a layer-based automated fabrication process for making scaled 3-dimensional physical objects directly from 3D-CAD data without using partdepending tools" [1].
In the past, research in terms of AM has focussed especially on technical aspects. Research at the interface between AM as a fabrication process and other disciplines, such as logistics, has remained scarce. From a logistics point of view, AM enables many different opportunities for replacing classical production technologies and will change supply chains and value chains respectively. Products are printed locally, close to or right at the point of use. By that, a higher efficiency and shorter reaction times in the supply chain can be realized [2].

2. Why Offshore Wind Energy

One of the branches, which could highly be influenced by the AM-technology is spare parts logistics. With AM there is no need for abundant warehouse activities. Each part is only printed on demand. The idea is to combine the advantage of on-demand-production with spare part logis¬tics for offshore wind energy systems. The offshore wind industry is still facing a lot of challenges – especially the task to reduce the electricity production cost per mega¬watt has to be solved. One starting point is to optimize logistics processes – not only in the installation phase, but in the period of operations and maintenance (O&M) as well.
3. Research questions
The operation phase of a wind farm is planned to last up to twenty years. However, first experiences show, that the need to change components is more challenging and cost intensive as expected. In a logistics concept for O&M, aspects like the location of storage capacities (onshore or offshore?), lead times, weather dependency and capacity of service vessels or helicopters and platform or floatel solutions have to be considered.
When printing a spare part no sooner than it is needed, less storage capacities will be needed. Instead of producing parts onshore, spare parts could directly be printed on a vessel or a platform located in the wind farm. Thus, no time would be lost for weather dependant transports.
In the project "Additive Manufacturing and Maritime Logistics" ISL investigates to what extend AM could be used for printing (spare) parts offshore. Therefore, business models, technical and logistical require¬ments to enable printing parts offshore will be analyzed. In addition, possible consequences for harbour activities and maritime and hinterland transport chains will be evaluated. The results can be compared with the classical production and logistics approach.

4. References

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Acknowledgement

The cooperative junior research group on Computational Logistics is funded by the University of Bremen in line with the Excellence Initiative of German federal and state governments.

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PERFORMANCE OF MERRA DATA IN OFFSHORE WINDENERGY APPLICATIONS

Jörg Bendfeld, Stefan Balluff*

1. Introduction

In response, offshore wind plants become an important contributor of electricity generation from wind energy. By considering the large potential of offshore power available in the North Sea, several many german projects are in process. For economic and technical reasons, the determination of wind conditions is an important stage in the frame of the offshore wind plant design. Organisations want to know in an accurate way the potential energy production of their investments and engineers need information about the wind conditions occurring for an optimum design and the selection and layout of the wind turbines and the parks. Therefore, it is necessary to get estimations of the wind conditions for the energy output determination of offshore wind plants. These wind estimations can be produced from long term wind observations measured nearby the location where the wind farm would be established but currently such long term wind observations are missing. Therefore innovative methods of wind energy estimations have to be used.

2. Merra-Data

MERRA is a NASA reanalysis for the satellite era using a major new version of the Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5). The Project focuses on historical analyses of the hydrological cycle on a broad range of weather and climate time scales and places the NASA EOS suite of observations in a climate context. [1]
Retrospective-analyses (or reanalyses) integrate a variety of observing systems with numerical models to produce a temporally and spatially consistent synthesis of observations and analyses of variables not easily observed. [2]

3. Object

At the early stages of offshore wind farm developments wind farm developers rely on limited knowledge regarding the wind resource on sites. Measurements could fill this gap. But often there isn't enough time or Money to build up a met mast.
In this paper the Quality of Merra-data for offshore-wind purposes will be investigated. The Merra data will be compared with the "real" offshore data of several offshore met masts in the North Sea and the Baltic. The wind speed, the distribution and the wind direction were examined.
The resulst show that some stations show a good correlation between the Merra data and the measured data. While some of the results show that some improvements are necessary.

3. References

[1] http://gmao.gsfc.nasa.gov/research/merra/
[2] http://gmao.gsfc.nasa.gov/research/merra/intro.php

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SUPPLY CHAIN CONCEPT FOR INDUSTRIAL ASSEMBLING OF OFFSHORE-WIND-JACKETS

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1. Supply Chain Concept

1.1 Introduction

- High production costs/low production quantities put jackets at a competitive disadvantage compared to monopoles/XXL
- For jackets to be competitive a cost reduction of 30% is required
- One way for the jacket to become competitive is via an industrial abrication process
- Supply chain concept by Salzgitter AG
  - Cost saving by supplying prefabricated assemblies and usage of standardized pipes à modular design principle
  - Pre-fabrication by innovative solutions à automated welding, cutting and NDT processes
  - Challenges
    - Fabrication of complex, heavy structures (K, X-nodes)
    - Guarantee of dimensional accuracy and reliability.

1.2 Modular design principle

I. Supplying of standardized pipes
  - High dimensional accuracy and lower cost compared to tailor-made pipes

II.Pre-fabrication of assembly components (K, X nodes) Fig. 1.2
  - Reduction of cost by:
    - Automated welding strategies à less welding time
    - Delivering of already approved components
    - Lower assembly time for fabricator
    - Lower NDT cost due to better accessibility

Fig. 1.1

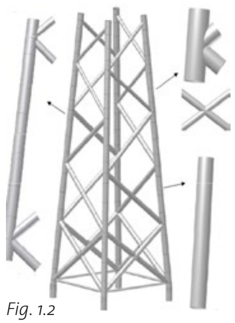

Fig. 1.2

2. Cost savings

up to 30 % by optimized assembly strategies

3. Feasibility study:

automatic welding of nodes

4. Results – next steps

RADIAL BOLTED CONNECTION BETWEEN MONOPILE AND TRANSITION PIECE

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1. Introduction

Currently, the connection between monopiles and transition pieces of offshore wind turbines is implemented with grout connections. The construction of grout connections is critical because a long curing process is required while often only short timeframes are available due to external conditions like changes in weather [1]. Changes in external conditions during erection introduce uncertainty regarding quality of the grout. This leads to increased installation time and costs. Currently available alternatives using bolted connections experience significant fatigue damage in welding during construction and require shimming and special bolts [2].

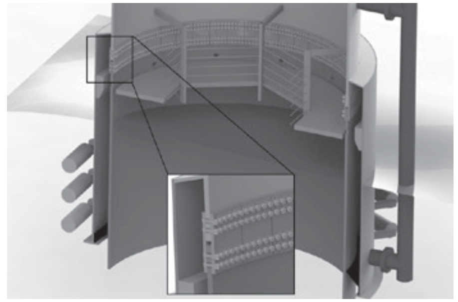

Fig. 2: Radial bolted connection

These issues are addressed by the design of a radial bolted connection. For the development of the proposed bolted connection, the most important boundary conditions depend on the capability to reduce costs. Hence, a connection using only standard bolts without restrictions on the number of bolts is chosen. Bolted connections show a high degree of standardization. After determining the type of connection, a detailed design for the implementation of the bolted connection is derived. In the proposed design the bolts are not subjected to fatigue stresses. The design is thereafter evaluated considering installation costs and potential optimizations of the design.

2. Radial bolted connection as alternative

The application of the radial bolted connection reduces the planned installation time and the risk of failure by reducing uncertainty in the fatigue resistance compared with grouted or bolted connections using welded flanges. In addition, financial risk due to unplanned project delay is reduced.
The connection is implemented by plate segments that are pre-mounted on the inner and outer sides of the transition piece. The diameter and the thickness of the monopile and the transition piece are equal around the connection area. The transition piece is aligned with the monopile. The bolts are inserted from inside the monopile. By pretensioning the bolts, the contact between monopile and transition piece is established by friction.

The application of the design can be used for both hammering and vibrating installation.
Detailed design optimizations could allow further cost reduction. Pile driving analysis of the monopole and optimizations regarding foundation steel mass reduction and installation process are planned. First results of these investigations will be presented.

3. References

[1] Dr. C. R Golightly, Geotechnical and Engineering Geology Consultant (2011): Monopile Grouted Connection Failures
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GEOTECHNICAL STABILITY VERIFICATION OF OFFSHORE FOUNDATIONS WITH RESPECT TO SCOURING IN THE NORTH SEA IN ACCORDANCE WITH BSH

Alireza Ahmari, Eka Fitti Paldi*

1. Introduction

1.1 Wind Farms in the North See
Wind farm projects in the German

North Sea EEZ (see Fig. 1) contain a large number of heavy turbines and platforms with overall height up to 150 metres and a total weight up to 280 tonnes.
Due to the importance of foundation-soil bearing system for such heavy offshore structures, verification of foundation stability and design requirements are, from geotechnical point of view, necessary. This should consider the measured scour depth around the foundation elements by means of bathymetry survey. The scour development, which is a consequent of hydrodynamic-morphodynamic interaction, is activated by wave- and/or current-induced circulation around the foundation structure at the seabed (see Fig. 2).

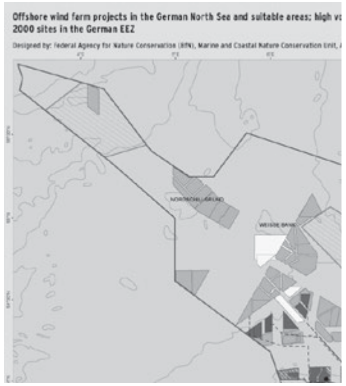

Fig. 1: Map of offshore wind farms in the German North Sea EEZ

2. Scope of Work

2.1 Purpose of the presented Work
The proposed paper will show verification method of foundation stability from certifier's point of view based on a case study considering the scour development, which has to be derived from the results of the bathymetric survey to be performed in accordance to the BSH Standard [1].

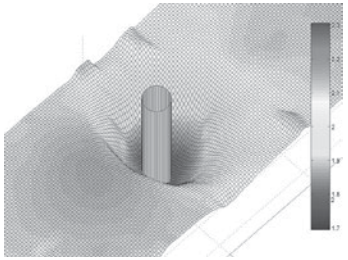

Fig. 2: Wave induced scour around a monopile structure after passage of 3.000 waves (Measured in Large Wave Channel by Coastal Research Centre (FZK) in Hanover, Germany)

2.2 Methodology
The stability of offshore foundations (Characteristic suction caissons and monopile structure) has been verified by means of a 3D numerical ANSYS-model for the Ultimate Limit State (ULS).
As unfavourable load case: maximum moment has been considered in a post installation situation with degraded soil profile and expected scouring.

2.3 Results
Displacements of offshore foundation for maximum moment have been illustrated.

3. References

[1] BSH Standard Ground Investigations for Offshore Wind Farms, Feb. 2008

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PROCESS FMEA: PREVENTIVE RISK MEASURES FOR OFFSHORE WIND FARM PROJECTS

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1 Project related risk management

Several project developers have already gained extensive experience with the installation of offshore wind farms and were thereby faced with a significant amount of major failures in various contract packages.
One lesson learned by the project companies is to go for a higher vertical integration of risk tracing. Even if certain risks are contractually shifted on to contractors, liability limitations usually do not allow the full recovery of heavy losses. Moreover, a simple contractual transfer of risks makes it sometimes even harder to intervene, if necessary.
Even first-hand experience with recent failures does not necessarily mean to have suitable preventing measures for future incidents in place. Moreover, the next project most probably employs different contractors and features new technologies. Even the company's project team might have changed.
Therefore, a systematic and sustainable approach to identify and deal with risks is essential for the own learning curve and increases the confidence of the stakeholders in an improved control of project risks.

2. Implementation of a Process FMEA

This paper describes the gradual implementation of a Process Failure Mode and Effects Analysis (P-FMEA) for an offshore wind farm project:

- Choosing the FMEA type
- Determining the right time to start
- Setting-up the FMEA core-team
- Analysing the system, processes and malfunction structures in expert workshops
- Utilising Risk Priority Numbers to quantify results

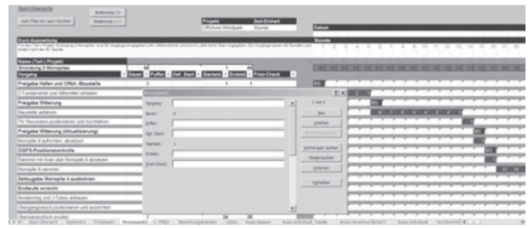

Fig. 1: Software supported process analysis

The P-FMEA follows a five-step-approach:

1. System analysis
2. Process analysis
3. Failure analysis
4. Risk analysis
5. Optimisation

Experience shows that initial project planning consist of hundreds of processes which subsequently diversify into thousands of sub-processes. To manage the large amount of input data, a spreadsheet-based application is used to guide the FMEA-team through a structured process (Fig. 1).
Such application supports the input, processing, analysis, documentation and presentation of all data. This ensures proper documentation and facilitates the tracking of agreed actions. Quantified results are suitable for further processing by the commercial risk control.

3. Results

What seems dauntingly complex at first sight turns out to be manageable by applying common standards of every-day project management – in a broader but also much more systematic manner.
The P-FMEA proved to be capable to identify risks, improve failure detection, and develop preventive measures. Furthermore, the P-FMEA is advisable to clarify in- and external responsibilities, processes, interfaces, and respective interrelations for the entire project.

ADVERSE WEATHER RISK: IMPACT, ASSESSMENT AND MITIGATION APPROACHES

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1. Introduction to Weather Risks

1.1 Background

Adverse weather has a high impact on the execution of offshore activities. Project progress delays caused by unfavorable weather conditions are common and generate high costs for additional or extended short term vessel charters. Currently there are limited commercial and scientific tools available to efficiently analyze weather impacts.
However, offshore activities are restricted by known limitations (e.g. sea state, wind speed, currents). The State of the Art technologies for weather risk analysis are investigated, summarized and presented.

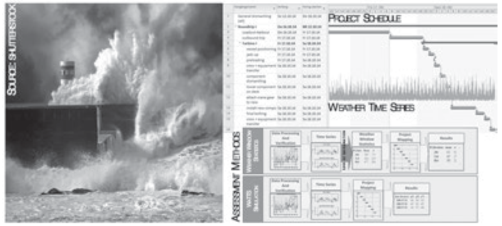

Fig. 1: Weather Influence

1.2 Weather Risk Mitigation Approach

Offshore activities are restricted by known limitations. The Weather Time Series Scheduling (WaTSS) method provides an approach to determine the weather impact on offshore activities. Implemented in the COAST toolbox, a holistic and easy to use software for the daily work has been developed. The underlying approach uses long weather time series and corresponding weather limitations for each activity for the simulated execution of offshore activities. Furthermore boundary conditions (e.g. marine operation guidelines – DNV-OS-H101 – or forecast uncertainties) are considered. As a result the distribution of the activity/project durations are provided.

2. COAST Approach – Case Study

The approach is demonstrated for an example installation schedule for the Fraunhofer IWES virtual reference wind farm and compared to the initially described state of the art technologies.
The COAST toolbox facilitates the advantages of the WaTSS method and can be easily embedded in the daily work progress.
The method can be applied to all offshore activities for transport & installation (T&I), operation & maintenance (O&M) and decommissioning. Using a scenario approach a project plan can be optimized. In the end the COAST toolbox supports better informed, risk based decisions in order to optimize the project progress, cost and risk profile.

Fig. 2: COAST Software Approach

3. References

[1] M. Wiggert, J. Weigell, H.-G. Busmann: A sensitivity analysis approach for project scheduling in a weather constrained environment; Offshore Wind Operations 2012, Bergen 2012
[2] M. Dytczak, G. Ginda, N. Szklennik, T Wojtkiewicz: Weather Influence-Aware Robust Construction Project Structure, Procedia Engineering 2013

REALISTIC SCENARIO FOR THE DEVELOPMENT OF OFFSHORE WIND POWER IN GERMANY

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1. Background

More than 30 offshore wind farms (OWF) have been approved in the exclusive economic zone and in coastal waters in Germany by the end of 2014. Thus, approvals for construction and operation of more than 2,000 wind turbines exist. In 2015 nine projects will be commissioned after completion of construction works at sea.

2. Development of a scenario

Within the investigation a scenario with a time-based resolution of the development of construction phases in the next years and an outlook on the further development by 2020 was developed for the OWF in Germany. The study is based on the results of the "HyproWind" research project [1]. Furthermore, the adjustment of the targets for the offshore development in Germany as amended in the EEG 2014 [2] was considered. Only offshore wind farms which already have been approved were taken into account in the scenario. The availability of the grid connection is of particular importance for the time-based resolution of the scenario. The amendment of the Energy Industry Act (EnWG) at the end of 2012 has led to a fundamental system change in terms of the grid connection of offshore wind farms. The previously existing right for OWF project developers to have a grid connection ready at the completion date has been replaced by the planning criteria for the controlled development of infrastructure at sea on the basis of the "Bundesfachplan Offshore" (federal offshore scheme) and the "Offshore-Netzentwicklungsplan" (O-NEP – offshore grid development scheme). The stipulations of the O-NEP are therefore essential for the development of the scenario, besides the actual progress in terms of planning and realization of individual OWF projects. The assessment of the planning progress is based on the criteria for the grid connection of offshore wind farms defined by the Federal Network Agency and already granted grid connections, respectively.

3. Results of the investigation

The basis for the grid planning in the O-NEP is the so-called "start offshore grid". The start offshore grid comprises the operational offshore grid connections as well as the cable routes for the OWF with a valid consent for grid connection. The scheduled year of commissioning is specified for the respective grid connection projects in the O-NEP. The analysis shows that some grid projects (DolWin 3, BorWin 3 and BorWin 4) will not be ready for operation before 2017/2018. Furthermore, there are seven offshore wind farms already approved, for which the grid connection is only planned after 2020 according to the scheduled realization of the "offshore extension grid".
Most of the developments are planned with 80 wind turbines. Due to an expected optimization of logistics and installation process it is assumed for 2016-2020 that the installation of 80 foundations can be completed in only three quarters. The results of the analysis show that construction work for the installation of substructures for 15 offshore wind farms can be expected by the end of 2015. According to the estimation, the construction of another eleven offshore wind farms could start in the German North Sea by 2020.

4. References

[1] Realistische Hydroschallszenarien auf der Basis von Prognosemodellen und Monitoring für den Bau von Offshore-Windparks in der deutschen Nordsee, Hannover/Wilhelmshaven 2014
[2] EEG 2014

BOLTED JOINT LIFETIME MONITORING

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1. Introduction

Bolted joints are one of the most common elements in construction and design, and yet they are frequently the root cause of expensive structural failures. For an industry as young and exciting as wind energy joint failures can mean not only the loss of several million euros, but also a severe dent in its quest to achieve wider acceptance as a reliable and attractive source of energy. Conventionally, when engineers designed bolted joints they designed to load or clamping force, but thereafter assembly and inspection was purely guesswork based on torque measurement. The i-Bolt® technology allows precise direct measurement of load in fasteners. This is seen to be immensely useful for controlling the tightening process in production and subsequent inspection measurements, all with load accuracies 10 times better than conventional techniques. The end result is that engineers are now equipped to not only design to load, but also to assemble and inspect to load, with absolute confidence in accuracy.

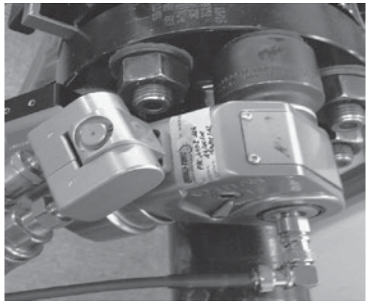

Fig. 1: tool equipped to work with i-Bolt technology

Fig. 2: i-Bolt® examples

1.1 Understanding Joint Failure

Most joint failures are not due to joint design or the fastener selection. More often they are the result of insufficient or inconsistent clamp load at assembly. Problems such as bolt fatigue or vibration loosening, which account for over 75 percent of all bolted joint failures, can usually be prevented by achieving and maintaining a correct level of clamp load in the joint. A variation in installed fastener clamp load of 30 percent is typical with tightening control methods based on the measurement of applied torque. With the i-Bolt® technology end users are able to tighten fasteners directly to load with ±3 percent typical accuracy using any kind of tool (Fig. 1), including high speed impulse and impact wrenches. All assembly torque, yield, and friction issues are completely eliminated. At any time after assembly and during the life of the joint, the operator will also be able to inspect the residual load in each joint in less than two seconds with ±5 percent and without disturbing the joint. With a 2D bar code laser etched on the surface (Fig. 2), provides each fastener with unique traceability and a link to a database of assembly and inspection history. Unlike conventional ultrasonics, this technology doesn't require parallel surfaces and is not dependant on transducer attachment procedures.

2. Summary

In conclusion, the technology is a big stride in quality assurance and preventive maintenance, as the end users can now measure load in the actual joint (without affecting it or changing it) to determine the installed loads achieved with their current tightening process. In addition, it provides traceability for each bolt. There is also the option for continuous load monitoring and the capability for real time field testing. Design engineers now have the potential of using smaller or fewer fasteners by tightening directly to load with i-Bolt®. The ±3 percent assembly accuracy allows them to utilize of the full strength of the fastener and verify they are achieving and maintaining that load in their joint designs throughout the life of the equipment.

RAVE UNDERWATER OPERATIONAL NOISE MEASUREMENTS IN THE OFFSHORE WIND PARK ALPHA VENTUS – FINAL RESULTS

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1. Introduction

The University of Applied Sciences Flensburg measured the operational underwater sound immission of the 5 MW offshore wind turbines in the wind park alpha ventus during their operation. The project was part of the RAVE research initiative and sponsored by the Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) founded on the basis of an act of the German Parliament. The question was: Is underwater noise of wind turbines in operation dangerous for marine animals, especially for seals and dolphins? First findings DEWEK 2012, final answers now.

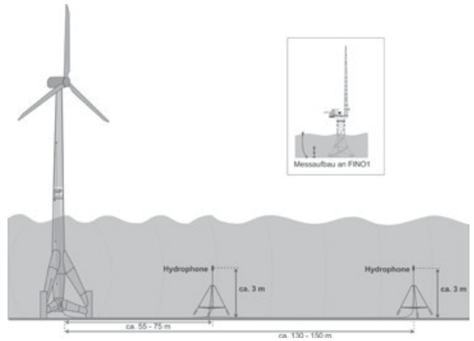

Fig. 1: Measuring setup: Turbine with foundation, two hydrophones in 75 and 150 m, acceleration sensors, data computer, top right measuring setup at FINO1

2. Measurement Setup

Several underwater hydrophones were installed in the wind park. Apha venus is in the North Sea, the water depth is 30 m. Two hydrophones were sited near one turbine and one hydrophone was sited at the research platform FINO 1, see Fig. 1. Several vibration sensors were installed in tower and foundation of two turbines to identify the noise sources. Measurements from 2010 and 2011 were evaluated.

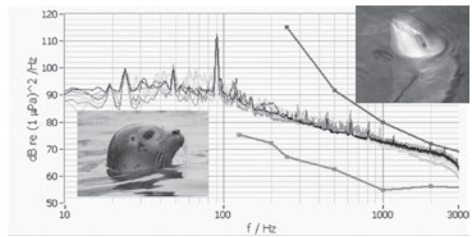

Fig. 2: Hearing threshold dolphin (upper line), seal (lower line), own measurements in wind park in between as 7 spectra registered with hydrophone R4-HR1 (all colors and black) position ca. 100 m to the nearest turbine AV04 and 800 m to the next turbine AV07, both turbines full load. Sources: Threshold data Kastelein 2002 and 2011 and Betke 2012. Pictures: Dolphin: Wikimedia AVampireTear Lizenz: CC-BY-SA-3.0 http://creati vecommons.org/licenses/ by-sa/3.0/ Seal: Aquarium GEOMAR http://aquarium-geomar.de/tiere/ luna. html, both access 5/2013

3. Results

The equivalent permanent noise level over all in the wind park is Leq 118 dB re 1 µPa. To get a comparative value in air subtract 62 dB. The result, 56 dB, is quieter than the noise in a dining hall.
The relation noise to power is detected.
All tonal noises are identified with the acceleration meters. The most significant tone with 90 Hz and its harmonics are generated in the drive train of one turbine, transported down the tower into the water. Fig. 2 shows the main result: Seven spectra in 100 m and 800 m distance to the nearest turbines at full power of all turbines. The hearing thresholds of dolphin and seal (upper and lower curve) are close. As result no detriment to these species is expected. Further the research shows that underwater noise measurement must be part of the permitting process to measure and in result to avoid noise to enhance the state of technology in turbine design. Furthermore the accumulated noise of wind parks will generate stress and should be monitored.

4. References

[1] van Radecke, H., Benesch, M. (2012): Schlussbericht zur Messung der Betriebsgeräusche von Offshore-WEA zur Bestimmung des Schalleintrags im Testfeld Offshore. RAVE Projekt Fkzeichen 0327687, http://opac.tib.uni-hannover.de/DB=1/ LNG=DU

ENVIRONMENTAL IMPACTS OF NOISE, VIBRATIONS AND ELECTROMAGNETIC EMISSIONS FROM MARINE RENEWABLES (MARINE RENEWABLES, VIBRATIONS, ELECTROMAGNETICS AND NOISE – MARVEN)

Frank Thomsen[1], Joachim Gabriel[2]; Andrew Gill[3], Peter Sigray[4], Alain Norro[5], Thomas Folegot[6], Michel Andre[7], Monika Kosecka[1], Denise Risch[8]

1. Introduction

In Europe and beyond, there are ambitious plans to install marine renewable energy devices, or MREDs, i.e. wind- wave and tidal power plants. The construction and operation of MREDs will lead to, among other things, the emission of electromagnetic fields (EMF), subsea sound, and vibrations into the marine environment. Migratory fishes that respond to natural environmental cues, such as the Earth's geomagnetic field move through the same waters that the MRED occupy, thereby raising the question of whether there are any effects of MRED on migratory and other fish species. Underwater sound impacts from MREDs have become a particularly important environmental issue. This is because water is an excellent medium for sound transmission. Pile-driving sound during construction of offshore wind farm monopiles and other foundations (e.g. jacket or tripod) is of particular concern as it reaches comparably high sound pressure levels and could have significant effects on marine mammal and fish species common in European waters.

Yet, there are many open questions with regards to impacts of MRED on marine life. These information gaps pose challenges to the implementation of MREDs.

2. The MaRVEN Project

In a project for the European Commission, Directorate-General for Research and Innovation, DHI is undertaking a study of the environmental impacts of noise, vibrations and electromagnetic emissions from MREDs (Marine Renewables, Vibrations, Electromagnetics and Noise – MaRVEN). MaRVEN will critically review the available scientific evidence and significance of those impacts and then make recommendations on solutions to mitigate or cancel the identified negative impacts. Here, we present findings of the project, both from the reviews as well as the extensive monitoring campaign that was undertaken during summer and fall 2014 and includes the first parallel measurement of EMF, Particle motion and sound pressure at two types of wind farm foundation (jacket and monopile).

[2] German Wind Energy Institute (DEWI, Germany), [3] Cranfield University (UK), [4] Swedish Defence Research Institute (FOI, Sweden), [5] Museum – Operational Directorate Natural Environment Management (Belgium), [6] Quiet Oceans (France), [7] Universitat Politècnica de Catalunya/Universitat Politècnica de Catalunya (UPC, Spain), [8] Scottish Association for Marine Science (SAMS, UK)

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REAL TIME UNDERWATER SOUND MEASUREMENT SYSTEM MAUI – PILE DRIVING NOISE ASSESSMENT AT SITE

Andrea Lübben[1], Friedrich Wilts[1], Tom Neumann[1], Karin Kloske[2]

1. Introduction

Anthropogenic underwater noise can be a significant pressure on marine mammals. Currently the construction of offshore wind farms causes the underwater sound level to increase because foundations are mostly erected by pile driving. In order to minimize the impact on marine mammals a limit of the sound exposure level of 160 dB re 1µPa in 750 m distance to the piling site is given by German federal authorities. During the installation of foundations the constructor is required to verify this compliance by measurements. The results of these measurements have to be provided within a few days after installation to the Federal Maritime and Hydrographic Agency (BSH).

2. Description of MAUI

In order to be able to monitor the actual underwater sound during pile driving DEWI developed the underwater acoustic noise measuring system MAUI (Monitoring System for Acoustic Underwater noise including Interactive Control and Data Transfer) which determines the sound pressure levels immediately in real time. Furthermore this data is transferred instantaneously from the system to a vessel or platform located at the construction site. There the sound pressure level is presented graphically with a delay of only a few seconds after the noise emission.
The range of the data connection reaches up to five km. MAUI works energy efficiently as it only starts measuring when detecting a specific sound pressure threshold and stays in sleep mode the rest of the time.

Once installed MAUI provides automatic reporting of the sound immission at 750m and provides immediate information. With this real time transfer of sound pressure levels noise mitigation systems or piling programs can be adapted directly, in order to find the best approach of minimum noise immision in the harbor porpoise habitat. Furthermore it can be used to perform parameter studies of equipment and different techniques at site as the result of adaptations is reported immediately.

3. Offshore test of MAUI

Besides several offshore tests of the systems components the first tests of MAUI was performed in July 2013 during an installation trip to the offshore wind farm Dan Tysk. At the site MAUI operated reliably and constantly. Data analysis as well as data transfer functioned continuously. The set up of MAUI and results from these first measurements will be presented at the conference.

4. Acknowledgements

This work was kindly funded by Vattenfall Europe Windkraft GmbH.

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ASSESSMENT OF AMPLITUDE MODULATION OF WIND FARM NOISE AND AN APPROACH OF MITIGATION

Joachim Gabriel, Steffen Vogl, Thomas Neumann
DEWI GmbH, Wilhelmshaven, Germany

1 Introduction

Amplitude modulated aerodynamic noise (AM) is the common ground of many complaints about noise from wind farms.

In order to understand these complaints, it is necessary to assess the "phenomenon AM" from audio recordings of the perceived noise.

2 Assessment of Amplitude Modulation

AM is a temporary phenomenon and it is difficult to perform a temporary sound recording just at the time of annoyance. DEWI owns a collection of audio recordings of amplitude modulated wind turbine noise including own far field measurements and noise recorded by residents of wind turbines at their houses.

In order to get an idea of frequency, duration and intensity of AM in wind turbine noise, the audio files have been listened to and analysed by numerical evaluation tools, to quantify the physical AM and the perceived AM.
Within the tool the modulation depth ΔL was used as a parameter for AM. The modulation depth ΔL is defined as the difference between the maximum and minimum sound pressure level. In addition a second parameter for AM quantification – fluctuation strength F* – was used. F* is a psycho acoustically motivated measure, representing the perceived AM. The origin of F* is the fluctuation strength, developed by Zwicker, which was slightly modified for the analysis of wind turbine noise.

- Still the data set is rather small. Analyses of a set of recordings (28 different days) show:
- Sometimes modulation is only sporadically present.
- Modulation is not always sinusoidal, but can have different shapes.
- Typically the modulation is strongest in the frequency range around about 160 Hz.

From all recordings, those made in the night time contained the highest modulations.

AM attracts the attention and even if it is a temporary phenomenon, investigations of the causes of far field AM are worth to be carried out. An improved version of the AM assessment tool – featuring long term data analysis – will help to identify AM critical operational conditions.

3 Mitigation of Amplitude Modulation

Future detailed investigations of AM need synchronised wind (e.g. LIDAR), wind turbine and sound data. Seeing AM as temporary partial stall caused by wind shear, an approach of AM mitigation is to fill the resulting gaps of noise by active devices synchronised with the blade passing frequency. Possible solutions might be loudspeakers, but also modified active elements to change the shape of a small part of the rotor blades (as tested in some research projects) might be used.
Mitigation of AM by modification of the operational mode must be paid by leaving the optimum of the energy output. Detailed knowledge about AM critical operational conditions will reduce these costs.

IEC 61400-11 ACOUSTIC NOISE: DIFFERENCES BETWEEN EDITION 2.1 AND 3.0

S. Vogl[1]

1. Introduction

In 2012 the edition 3 [1] of the IEC 61400-11 noise measurement standard was released, relieving the former edition 2.1 [2] from 2006. The new edition gives more details about acoustic behavior of a turbine, and results are better reproducible between different days of measurement and different institutes (using different hardware and software).

2. Issues for the Measurement

For edition 2, theoretically no turbine data needs to be recorded and only a wind-met-mast and a sound-level-meter is enough, because measurement of power, nacelle wind speed and rotor speed is not compulsory. Compared with this, these points are all required in edition 3.
Also the minimum requirements for a complete measurement are less in edition 2:
Wind bins 6 to 10 m/s <-> for edition 3: 0.8 to 1.3 times wind speed at 85% of Prated. For two out of six evaluations this meant that according to edition 2 the measurement was complete, whereas for edition 3 the data set was insufficient.

3. Issues for the Evaluation and Results

Regarding the sound power levels (SWL) Figure 1 shows the differences (ed2 – ed3) of up to 0.4 dB.
Regarding the highest sound power level (SWL), the differences were less than 0.2 dB.
Large differences occur for the tonality analysis. Taking only 2 minutes (ed 2) instead of all available data (ed 3) introduces large variance; Figure 2 shows the tonal audibility ΔLa for one distinct tone of a turbine across the wind speed at 10 m: whereas for edition 3 the tonal ability remains more constant over wind speed, edition 2 shows large fluctuations. The standard deviation σ is approx. doubled.
Also, the tolerance for tones of same origin is in edition 2 too low. When using only 10% of the critical bandwidth there are cases for which tones are not combined to one tone of same origin. Regarding edition 3, it was also in one evaluation for one tone, that the 50% tolerance was a bit too high and two distinct separate tones were wrongly seen as one. Reduction to 25% solved the problem.

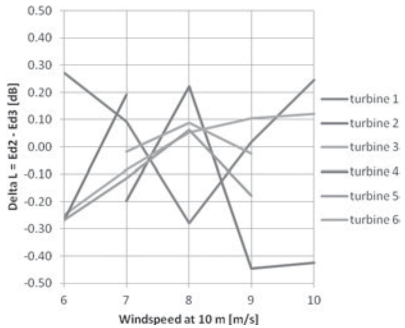

Figure 1

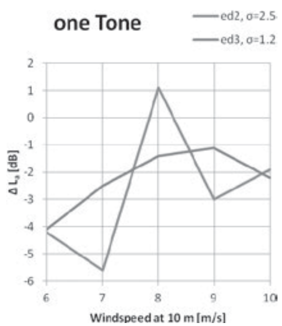

Figure 2

4. References

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[2] IEC 61400-11, Ed. 3 „Wind turbines – Part 11: Acoustic noise measurement techniques". 2012-11.

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